THE JOURNAL OF INDUSTRIAL HYGIENE

PUBLISHED MONTHLY

VOLUME VII JULY, 1925 NUMBER 7

ACUTE DERMATITIS AMONG PAINTERS EMPLOYED IN AN INDUSTRIAL PLANT*

J. A. TURNER, PH.G., M.D.

Medical Director, Laidlaw Works, Worthington Pump and Machinery Corporation, Cincinnati, Ohio

THIS report is based on a clinical study of five patients who reported at the plant hospital for relief from a troublesome skin eruption, and also on certain animal experiments which were conducted to ascertain the substance or substances responsible for this disease.

The work performed by the painters consists of painting iron castings both before and after they are assembled. The paint is applied with an ordinary hand brush and during this process the paints and solvents get on the hands and arms of the painters. There are in all about seven men employed at this kind of work.

At the close of the workday the painters clean up; a favorite method among them for removing the paint from the hands and arms is to use turpentine, thinner, or naphtha. At one time they used wood alcohol for this purpose, but they discontinued using it because they claimed that it was too irritating to the skin and that the odor was disagreeable. Certain of the men, when questioned, admitted the possibility of carelessness in thoroughly washing the hands with fresh water after using the paint solvents; this was particularly apt to occur when in a hurry to dress and catch the street car.

There are a number of paint substances and solvents used by these men in their work: namely, turpentine, naphtha, white paint, iron filler, thinner, and sealer. In respect to their constituents, such information as could be obtained showed that the turpentine is bought as commercial

* Received for publication March 30, 1925.

turpentine; the white paint is a composition of zinc oxide, white lead, and solvents; the iron filler is a mixture of carbon black, petroleum, and turpentine; the thinner is made at the plant by the painters and consists of equal parts of turpentine and naphtha; and the sealer is composed of drop black with petroleum for thinner. It was impossible, on account of trade policy, to ascertain from the dealer the exact composition of these substances. Our facilities at the hospital did not permit of a chemical analysis, although it is realized that such an analysis would greatly add to the value of this report.

Case Histories

Case 1.—W. B. has been employed as a painter for the past sixteen years. He gives a history of having had more or less trouble with his skin since working at his trade, and he expressed the opinion that the turpentine and the thinner that he got on his hands and arms were responsible for the dermatitis. He relates that in 1923 he suffered a very severe attack. The eruption at this time, according to his statement, involved the backs of the hands and forearms, extending nearly to the elbows. The eruption was rather pronounced on the inner surfaces of the wrists. The eruption appeared abruptly; at first the skin felt dry and irritated, and there was also a sensation of heat. Within twenty-four hours the affected parts contained many small blisters which were filled with a clear fluid. The blisters continued to enlarge until there was a considerable number of large, irregularly shaped ones. Itching at times was intense and in an effort to relieve this symptom the patient broke many of the blisters. He further claimed that the treatment applied appeared to aggravate the condition to such an extent that he was unable to work for a period of fifteen days.

On Oct. 6, 1924, he presented himself at the hospital for treatment for what he claimed was a recurrence of the skin affection identical with that which he had had in 1923. He said that he often had had little areas affected but because they were mild he had not sought treatment, but that this attack was so distressing that he could not continue to work unless he had some relief. At this time the backs of both hands and the outer and inner surfaces of the forearms halfway to the elbows were affected. The areas were covered with both small and large blisters containing a slightly turbid fluid. Where the blisters had become broken the base was much inflamed and bathed in a turbid fluid. Where the blisters had been broken for twenty-four hours or longer healing was in progress as evidenced by dryness and beginning desquamation. There was a moderate degree of edema of the affected area. Burning and itching were the symptoms most complained of. There was evidence of the patient having scratched himself with his finger nails. The patient claimed that the blisters at first were about the size of a pinhead, but that they rapidly increased in size, some of them having a measurement of $1\frac{1}{2}$ inches in length and from $\frac{1}{8}$ to $\frac{3}{8}$ of an inch in height.

Questioning this patient in regard to the methods he followed in cleaning up disclosed that he used either turpentine or thinner and sometimes naphtha for removing the paint from his hands and arms; this was followed by soap and water. He admitted that at times he probably was careless in washing off the solvents used.

The treatment of this case consisted in advising the patient as to the proper way of cleaning up, and to discontinue the use of paint solvents unless care was exercised to remove the solvent thoroughly with soap and water and then to rinse thoroughly with clear warm water. The medical treatment consisted of the application, twice daily, of a 1:1,000 solution of potassium permanganate. Improvement was rapid and uncomplicated. Cure was established on the expiration of ten days.

Case 2.—A. S., aged 49, has been employed in the paint department for the past two years. On Oct. 9, 1924, he reported at the plant hospital for treatment of what he called turpentine poisoning. He based his

diagnosis on the fact that he had been using either turpentine or thinner to remove paint from his hands and arms and that the dermatitis followed their use. Examination disclosed an eruption involving the back of the hands, the wrists, and extending halfway up the forearms. The eruption consisted of irregularly shaped areas, some of which were raw and exuded a small amount of serous fluid; others were dry and scaly. The intervening skin was normal in appearance. The patient claimed that the eruption began abruptly with a burning and itching sensation. Small blisters quickly formed and some of them grew to considerable size. Within two or three days these blisters became broken, leaving raw, tender, and inflamed sores. The application of potassium permanganate solution and advice in regard to cleaning the hands resulted in a rapid and complete cure.

Case 3.—J. H., aged 25, had been employed as a painter for about a year and a half. On Oct. 9, 1924, he reported for treatment of what he called turpentine poisoning. The eruption involved the backs of both wrists and was identical in appearance with that described in Case 2. This patient claimed that of late he had been using either turpentine or thinner for removing paint from his hands and arms and that before using these substances when cleaning up he did not have any trouble with his skin. The application of potassium permanganate solution and the discontinuance of the use of paint solvents when cleaning up resulted in immediate relief and a prompt cure within a week's time.

Case 4.—W. K., an apprentice boy, reported on Jan. 12, 1925, for treatment of a skin eruption located on the dorsal surfaces of the wrists and forearms and extending as far as the elbows. The affected areas were inflamed, rough, and scaly, with here and there a small blister about the size of a pinhead and containing a serous fluid. There was considerable itching and evidence of the patient's having scratched himself. Questioning revealed that the patient had lately been using naphtha to remove grease and oil from his hands and arms. This case rapidly responded to the application of potassium permanganate solution. The patient was advised against the use of paint solvents when cleaning up, with the result that there has been no return of the trouble.

Case 5.—A. W., aged 18, an apprentice employed in the pattern shop, reported March 9, 1925, for treatment of a dermatitis which affected the backs of both hands, being most prominent on the backs and sides of the fingers. The day before the appearance of the eruption he cleaned a machine, using cotton waste saturated with naphtha. He admitted that he did not observe particular care in washing off the naphtha. That night his hands felt dry and there was an appreciable degree of burning. The following day the affected parts were covered with a countless number of pinhead sized blisters containing a serous fluid. Itching and burning had increased in intensity. On the third day many of the blisters had become broken, probably as a result of scratching. From the raw areas there was an exudation of serous fluid. The application of potassium permanganate solution gave immediate relief from the burning and itching. Continued application of this remedy resulted in prompt cure within a week's time.

Animal Experiments

The cases cited above show that these men are exposed to a number of paints and paint solvents. The evidence presented tends to point to the solvents as the causative factors in causing the skin eruption. It was thought that animal experiments might aid in increasing our knowledge with regard to the action of these substances and might show which of them could be charged with causing the trouble among the painters. To this end guinea-pigs were obtained and prepared. The hair was cut from the lower part of the back, covering an area about 2 inches in diameter. Cutting the hair with scissors did not permit removing the hair as close to the skin as would

clippers or shaving. Shaving was not resorted to, however, for in doing so the skin might be injured and it was desirable to have an unirritated skin on which to apply the paint or solvents.

The paints and solvents used were: iron filler, sealer, white paint, turpentine, thinner, and naphtha. The constituents of these substances, so far as known, has been described. The samples used in these experiments were obtained from the stock used by the painters. The experiments consisted of daily application to the clipped areas on the guinea-pigs for twenty-five successive days. The animals were then kept under observation until they had returned to normal.

Iron Filler.—The iron filler was applied with a cotton-covered applicator and thoroughly rubbed into the skin. No effect was noted until the seventh day, when it was found that there were a number of small areas which were denuded of hair. There appeared to be no inflammation although there was evidence of some desquamation of the superficial layer of skin. During the following days the denuded areas increased in size until the eleventh day, when the entire area was completely devoid of hair. The skin at this time was slightly rough, but was free from any signs of inflammation. The application of the filler to the denuded area was continued until the expiration of the twenty-fifth day; at this time the skin did not show any further change, and so the experiment was concluded.

Sealer.—Daily applications of sealer to another animal developed a reaction by the fourth day, but on the following day this had practically disappeared. On the eleventh day a considerable portion of the area was denuded of hair. There was an appreciable amount of desquamation of the superficial layer of the skin, but there was no inflammation. The application of the sealer was continued daily until the twenty-fifth day; it was then discontinued because no further reaction occurred.

White Paint.—The white paint was applied in a thin layer over the clipped area. On the seventh day it was found that the skin was as clear of hair as that in the preceding cases. There was no inflammation and the desquamation was even less than with the foregoing animals. On the twenty-fifth day the application of the white paint was stopped, for by this time the skin presented the same appearance as it did on the seventh day.

Turpentine.—The first and subsequent applications of turpentine appeared to irritate the animal the instant it came in contact with the skin; this occurred in spite of the fact that there would be no visible evidence of it in the skin, but the behavior of the animal was sufficient to show that the application bothered him. On the seventh day there was visible evidence of skin reaction as manifested by a mild grade erythema. On the eleventh day there appeared several small areas of skin denuded of hair; the skin was rough and red. During the succeeding days the roughness of the skin somewhat increased. There was also marked desquamation of the superficial layer of the skin and loss of hair. This condition

progressed until on the fifteenth day, when the whole area was entirely denuded of hair. This area was enlarged simply by extending the application of the turpentine to the margins of the denuded area. During the succeeding days the skin was markedly inflamed, rough, dry, and, in many places, cracked. There was also evidence of the animal's having either scratched or bitten itself probably in its effort to relieve the irritation. On the twenty-fifth day the application of the turpentine was discontinued, as the reaction did not increase in intensity.

Thinner.—This thinner, as has been stated, is made up by the painters and consists of equal parts of turpentine and naphtha. The reaction produced by this mixture was practically identical in appearance with that of the turpentine. With each application of the thinner it obviously irritated the animal, and this irritation persisted for a few hours as shown by the animal's actions. On the fifth day it was seen that the solvent had produced an inflammatory reaction. There were a few places where the animal had either scratched or bitten itself. On the eleventh day there was marked desquamation of the superficial layer of the skin. On the following day there appeared many small areas denuded of hair; this loss of hair progressively increased until on the fifteenth day, when the entire area was clear of hair. The skin at this time was very rough, inflamed, and dry. Applying the thinner to the margins of the denuded patch increased the size of the patch. During the succeeding days the thinner did not increase the changes in the skin; on the termination of the twenty-fifth day the experiment was, therefore, stopped.

Naphtha.—The naphtha was applied in the same manner as were the other substances. No reaction other than immediate irritation, as noted with the turpentine and thinner, attended the first few applications. On the eleventh day desquamation of the skin began and loss of hair was noted as with the other animals. This condition progressed until on the fifteenth day, when the entire area was completely denuded of hair. The skin at this time was dry, rough, and moderately inflamed. As with the other animals, the denuded area was increased in size by extending the application of the naphtha to the edges. The subsequent applications to the denuded area continued to irritate the skin. The presence of scratches or bites testified to this fact. By the expiration of the twenty-fifth day the reaction did not show any further change beyond that already described, and so the application was discontinued.

Control Animals.—Control animals prepared in a similar manner by cutting the hair were used in this experiment. When the paint or solvent was applied it was allowed to remain in contact with the skin for from thirty minutes to one hour and was then removed. The paints were removed with turpentine, thinner, or naphtha; the area was thoroughly washed with soap and water and finally thoroughly rinsed with clean warm water, and then the skin was dried. These animals did not show any skin reaction. The clipped hair

continued to grow, so that by the expiration of a couple weeks it was as long as it was before being cut.

When the applications of the paints or solvents were discontinued on the experimental animals they quickly returned to normal; that is, all signs of irritation disappeared and the hair began to grow on the denuded areas so that by the end of three weeks it was as long as it was before being cut.

Conclusions

Paint solvents are capable of producing a dermatitis unless proper care is used in removing them from the skin. This can best be accomplished by the use of soap and water and then thoroughly rinsing with clear warm water and seeing that the skin is dried.

The solvents—turpentine, thinner, and naphtha—appear to be the chief offenders in producing the dermatitis in the group of cases presented in this report. In Cases 4 and 5 naphtha was the only solvent to which the patients were exposed. The eruption appeared only on the hands and forearms as they were the only parts exposed. The eruption is characterized chiefly by a dry skin. Within twenty-four hours after exposure many small blisters are formed containing a clear serous fluid. There is a marked tendency for these blisters to coalesce and form very large ones. When the blister is broken, an inflamed base is left from which exudes a serous fluid. The predominant symptoms complained of are burning and itching. Healing is attended with an appreciable amount of desquamation. A 1:1,000 solution of potassium permanganate applied daily to the eruption gives immediate relief from the burning and itching and at the same time promotes healing.

The animal experiments showed that both the paints and the paint solvents when applied daily have a depilatory effect which in the case of the paints was complete in from seven to eleven days, and with the turpentine, thinner, and naphtha in eleven days. The paint substances did not produce any marked skin reaction other than removing the hair; the solvents in addition produced some inflammation. The desquamation of the superficial layer of the skin was not so marked from the effect of the paints as it was from that of the solvents. Blistering of the animal's skin was not produced; with the patients this was one of the constant objective symptoms.

Workmen who handle and use paints and paint solvents should be advised as to their possible effects on the skin and should be instructed how to clean up at the close of the work period. The use of paint solvents in removing paint, grease, and oils from the hands should be discouraged.

FORTY-TWO OCCUPATIONAL DISEASE HAZARDS IN ONE INDUSTRY: THE TANNING INDUSTRY AS AN EXAMPLE OF THE MULTIPLE HAZARDS IN INDUSTRY*

DOROTHY K. MINSTER, A.B.

Cincinnati, Ohio

INTRODUCTION

THE average industrial physician working in one more or less restricted field of industrial medicine is apt to believe that occupational diseases or occupational disease hazards are the exception rather than the rule in industry. Or he may believe that an industry may have one occupational hazard peculiar to it. To disprove this assumption, and as a matter of information or reference, we have studied and collected a list of all the potential occupational diseases and their causes in one particular industry—the tanning industry. We believe that this industry has a greater variety of occupational hazards than almost any other one, although there are few industries which will not present a similar list. Our list includes forty-two processes or substances which may cause and in many instances do cause disease among the exposed workers.

Before detailing these hazards, we must point out certain limitations, or reservations. In the first place, we recognize that tanning is not a highly standardized process; that, quite on the contrary, it is an individual one, varying with practically every manufacturer. There is no standard recipe for tanning hides. Many ingredients used in this country are not used in others and *vice versa*. Processes vary within just as wide limits in the tanning of various kinds of leather. Sole leather is tanned by a process generally quite different from that used for belting or harness leather. Light leathers, such as chamois, kid, etc., are produced by a tanning process quite different from either of the above; and so it goes.

Because of these facts we have not sought to list the occupational diseases either process by process, or industry by industry, but merely to give a compilation of the hazards that may result from the processes which are employed in the common methods of manufacture. In order, however, to make the subject more comprehensible we have divided the processes into stages of manufacture.

STORAGE

Occupational disease in the tanning industry to most people means anthrax (1).[1] This is more commonly

*Received for publication March 30, 1925.

[1] The numbers running through the article indicate the sequence of hazards.

found in the first stages of the industry on the crude hides, than at later stages. We need not dwell on the causes of anthrax, its prevalence, etc., since there is a vast amount of material available on this subject. Suffice it to say that, owing to the regulations as to killing, curing, and importation, anthrax is far less prevalent today and, because it is so well known, it can be readily eliminated.

Poisoning from sulphuretted hydrogen (2) may occur among men unloading green hides from box cars, or among men working where green hides are stored. This gas may result from decomposition of organic matter.

Cyanide poisoning (3) has been known to occur from gas lime in the storage of hides.

Arsenic poisoning (4) may result from the handling of arsenic-cured hides. This method is in general use today for imported goat skins, and is still used occasionally on other types of hides from such countries as New Zealand, Italy, China, etc.

Mercury dermatitis may occur in the handling of hides soaked in bichloride of mercury (5) solution (1: 1,000).

The almost universal method of curing hides, now in practice, is that of salt (6) curing. This method may also cause some difficulty though it is not so severe as the types suggested above. Workers handling salt-cured hides develop a dermatitis or else salt burns.

Preparing

Soaking the Hides.—In the next stage we find that burns from caustic soda (7) and poisoning from sulphurous acid (8) are possibilities. These two ingredients are sometimes used to render the water into which the hides are put for soaking more suitable for that purpose. The solutions of caustic soda and sulphurous acid are generally rather dilute and any danger exists in the actual preparation of the soak waters rather than in the handling of the hides that have been soaked.

Dehairing the Hides.—After soaking, the hides are put through a process of dehairing. This is done either by sweating the hairs loose so that they can be readily scraped off, or by soaking the hide in lime. In the liming process, lime (9) burns are, of course, frequent. In addition there is a definite occupational dermatitis, known as "rossignol" or "le pigeonneau" found among the workers who are forced to keep their hands continuously immersed in caustic lime. This is characterized by "loss of substance and bright red, shining finger tips."[2]

Sulphide of soda (10), which is used either as a substitute or as an assistant to lime, may cause a dermatitis or burns.

Arsenic sulphide (11) is frequently added to the lime to hasten its dehairing action. It may result in a dermatitis as well as constituting the usual arsenic hazard.

Caustic soda (7), which is used in the unhairing process, will cause burns to the worker's hands, arms, etc.

The sweating method, which is the older and now less popular method,

[2] Kober, G. M., and Hayhurst, E. R.: Industrial Health. Philadelphia, P. Blakiston's Son & Co., 1924, p. 675. See also This Jour., 1924, vol. 6, Abstr. Sec., p. 38.

is dependent largely on bacterial action (12). Though these bacteria may not be responsible for occupational disease, they constitute a hazard in that a worker injured, even slightly, while engaged in this sort of work, is exposed to virulent infections. Let us pause while discussing this matter of bacteria in order to point out that in the care of the injured in tanneries it is frequently noted that infections of wounds are in more than normally high proportion. This is due to the fact that often fresh hides come into the factory in a filthy condition, contaminated with many harmful bacteria, tetanus for example.

Parasitic fungi (13) should also be mentioned here as a hazard, especially where sheep skins are being tanned.

Ammonium sulphide (14) is a by-product of the sweat chamber process. It is developed as a result of the high temperature in the chambers.

After the hides have been limed they are then delimed. Here again the danger of lime (9) burns exists in the handling of the hides before deliming has taken place.

At times deliming is accomplished merely by the use of weak acids, such as lactic acid (15). Lactic acid causes a mild dermatitis to the hands or exposed parts of some workers. If other acids are used they may cause burns of various kinds.

Red arsenic is often used as a deliming agent for soft leathers. The arsenic (4) as well as the arsenious acid which is formed constitutes a very serious hazard.

Other methods of deliming are those of "bating" and "puering." Here again the result is accomplished by bacterial action (12). These bacteria, as indicated before, may constitute a hazard.

A next step, or often a substitute step for these just outlined, is what is known as "drenching." This is an infusion of bran in hot water. The bacteria in the drenching mixture lead to the formation of some of the following products: lactic acid (15) which, as already indicated, may cause a dermatitis; methane (16); sulphuretted hydrogen (2); and carbon dioxide (17). Carbon dioxide is, of course, only a hazard when it reaches concentrations approximating 15 per cent. A case is cited of a man cleaning an empty vat who was found dead as a result of the excess of carbon dioxide.

Tanning

The hides are now completely prepared and are ready for actual tanning.

There are a variety of ways of tanning a variety of leathers. The vegetable tannins are made from different parts of various plants, such as sumac, oak bark, chestnut, quebracho, myrobalan, etc. These vegetable materials are leached in water, thereby extracting the tannins.

One tanning extract, which is a composite of many of these different plants, including myrobalan (18), is known to cause deep sores on the hands of the workers in the tanyard. The tannin extracted from myrobalan is believed to be responsible for these sores, because of its strong acid-forming qualities. These sores occur only when the skin is abraded. An eschar is formed which acts as a

foreign body and prevents healing until removed.

Sumac (19), another of these vegetable tannins, causes a definite dermatitis. Sumac is used in various other stages of tanning—in the finishing of sole leather as well as on the splitting machine. The dermatitis is similar in all instances.

Quebracho (20), too, causes a dermatitis. When quebracho is used it is usually treated with sulphites (21) among other alkalies, in order to dissolve the difficultly soluble bodies. These sulphites cause a dermatitis.

In the process known as acid hemlock tannage, sulphuric acid (22) again constitutes a hazard. It is used as a preliminary to the dipping of the hides into the liquors.

The chrome tannage method is far more hazardous than that of vegetable tannage. Chrome (23) sores result from the chromic acid which is liberated in this process, or from direct contact with the chromates.

Hydrochloric acid (24), which is allowed to react with potassium dichromate to form chromic acid, is another of the hazards in this process. Sulphuric acid (22) is also used in this connection, chiefly in the United States.

What is known as the one-bath process, which is in more general use today, does not appear to cause so much difficulty as the two-bath process. This may be due to the fact that free chromic acid is not liberated in the former. Free chromic acid seems to be a more harmful agent than the chromates.

Formaldehyde (25) is used as a method of tanning glove leather. In addition, it is often used as a disinfectant in the cleansing of storage rooms, etc. One worker walking beneath a room which had been disinfected in that way happened to look up and some of the formaldehyde splashed in his eyes. In a short time he was totally blind.

After the hides have been tanned they are again hung up to dry, galvanized tacks often being used in tacking them up. When the workers carry these tacks in their mouths, as they usually do, lead (26) poisoning is a possibility.

Finishing

Subsequent to the tanning, the hides go through various finishing processes. The chief chemical substances involved are sulphuric acid (22) and caustic soda (7). Sumac (19) is occasionally used in the bleaching process.

After bleaching, the hides are rendered more pliable by treating with fish or mineral oils (27), used generally with an emulsifier such as soap. These oils would cause no trouble if they were pure, but the impurities found therein, generally of bacterial origin, give rise to a furunculosis.

The chief hazard in the process known as "currying," which is part of the finishing process, is that of the leather dusts (28). These dusts affect the workers in two ways: They may irritate the mucous membranes; they may result in a definite anaphylactic reaction. Certain workers become sensitized to proteins in the leather, as may be demonstrated by strapping leather on to the arm. Where the leather has

come in contact with the skin, lesions are formed. Leather dusts may constitute hazards in other processes as well.

There are other types of dusts which are found throughout the tanning process which occasionally give rise to difficulties. Hair (29), in the handling of raw hides and in the scraping of hides after liming, is a possible hazard. Tanbark (30) in the grinding up of the bark in the yard is another instance.

Dyeing, Japanning, and Enameling

If the leather is to undergo a further process beyond that of graining or rolling, etc., such as dyeing, japanning, or enameling, an entirely new set of hazards and a widely varying set are brought into play. We are giving only those hazards which result from the chemicals in most common use. Lead (26) is perhaps the outstanding one. It is used in many of the pigments which go into the japanning or enameling processes. It is also used in what is known as "lead bleach," whereby a thin deposit of white lead sulphate ingrained in the leather gives it a whitish color.

Many of the aniline (31) colors are used in this part of the process.

Mercury (32) colors are also used in the dyeing or coloring of leather.

Amyl acetate (33), butyl acetate (34), benzol (35), naphtha (36), turpentine (37), butyl alcohol (38), and methyl alcohol (39) are variously used as solvents of these colors, each in its turn constituting a well-known industrial hazard.

Potassium ferrocyanide (40) is also used in the dyeing process to form Prussian blue on the skins. This process introduces the hazard attendant on all cyanides.

General Hazards

Carbon monoxide (41) should not be omitted from this list as a possible hazard. It is not connected with any process in particular but may occur wherever combustion is incomplete, as for instance near the furnaces. One case was found in a man driving a small tractor about the yard. The exhaust came right up under his seat and blew the gas in his face.

Another condition, while it is not really due to the tanning process but which was found like the above case in a worker in a tannery, is that of brassfounders' ague (42). A man who had been working on brass pipes in a tannery presented a typical case of poisoning.

Summary

By way of recapitulation, the hazards which we have enumerated are listed below.

1. Anthrax.
2. Sulphuretted hydrogen.
3. Cyanide poisoning.
4. Arsenic poisoning.
5. Bichloride of mercury.
6. Salt.
7. Caustic soda.
8. Sulphurous acid.
9. Lime.
10. Sulphide of soda.
11. Arsenic sulphide.
12. Bacterial action.
13. Parasitic fungi.
14. Ammonium sulphide.
15. Lactic acid.

16. Methane.
17. Carbon dioxide.
18. Myrobalan.
19. Sumac.
20. Quebracho.
21. Sulphites.
22. Sulphuric acid.
23. Chrome.
24. Hydrochloric acid.
25. Formaldehyde.
26. Lead.
27. Fish or mineral oils.
28. Leather dusts.
29. Hair.
30. Tanbark.
31. Aniline.
32. Mercury.
33. Amyl acetate.
34. Butyl acetate.
35. Benzol.
36. Naphtha.
37. Turpentine.
38. Butyl alcohol.
39. Methyl alcohol.
40. Potassium ferrocyanide.
41. Carbon monoxide.
42. Brassfounders'ague.

As we pointed out in the beginning some of these hazards are only potential. Many of them, however, have actually occurred in the course of our work in tanneries, and many of them are recorded in the literature on this subject.

A compilation such as this serves only to point out the danger points in this industry. Similar compilations for other industries, perhaps for most industries, could be made, because there is practically no industry today that will not present a similar multiplicity of hazards.

J. I. H.
July, 1925

THE SIZE-FREQUENCY AND IDENTIFICATION OF CERTAIN PHAGOCYTOSED DUSTS*

PHILIP DRINKER

Department of Ventilation and Illumination,
Harvard School of Public Health, Boston, Mass.

INTRODUCTION

IN THE damaging of lung tissue by the inhalation of dust—pneumonokoniosis—the size and the kind of the particles inhaled are of great importance. In the case of free, as distinguished from combined, silica, the dangerous particles are apparently limited to approximately 0.5 to 5 microns in diameter. Dusts made up of crystalline silica particles falling within this range are called by Mavrogordato (1) "phthisis-producing." Those smaller than 0.5 micron appear to do little or no harm in the production of lung fibrosis; whereas those which are larger do not reach the alveoli.

It is well known that endothelial cells containing dust are found in the lungs of men and animals exposed to dusty air. It is also common knowledge that these cells often occur in human sputum. In lung tissue or in sputum they can be identified and distinguished from epithelial cells by staining. It is still not definitely proved, however, that these cells and the dust they contain come from the alveolar area alone. Nevertheless, the burden of the evidence gathered from investigations in this field tends to show that dust occurring in endothelial cells, no matter where the cells are found, comes originally from alveolar tissue.

* Received for publication April 17, 1925.

PHAGOCYTOSIS

One of the most important methods of dust removal from the lung tissue is phagocytosis.

In his experimental studies relating to this subject, Fenn (2) used leukocytes from the peritoneal cavity of the rat. Suspensions of these cells were mixed first with uniform suspensions of particles of quartz and then with carbon, and both mixtures incubated at 37°C. In all cases, the size of the particles was accurately controlled by repeated settlings in water, and suspensions were stabilized by Acacia. Fenn found that particles of 4 to 5 microns were taken up more readily than smaller particles of 2 to 3 microns, and showed by calculation and experiment that these differences depended on the chances of collision between the cells and the particles. Finally, by a very ingenious technic, he showed (3) that carbon particles were phagocytosed about three times as readily as quartz, when equal sizes and concentrations of both dusts were exposed to phagocytic cells. In like

manner, he found that manganese dioxide was phagocytosed about twenty times as readily as manganese silicate—an observation with direct bearing on the phagocytosis to be discussed in this paper.

Phagocytosis and Pneumonokoniosis

It is well known that, of quartz and carbon dusts, the former is by far the more dangerous in producing lung damage, and Fenn has shown the latter to be the more readily phagocytosed. From this, it is interesting to follow out Haldane's (4) and Mavrogordato's (5) original suggestions as to the possibility of predicting the harmfulness of insoluble, inert dusts according to the readiness with which they are removable by phagocytosis. That is, are not those dusts which are most readily phagocytosed the least dangerous? If this is the case, lung damage by dust inhalation can be predicted, because selective phagocytosis can be studied both *in vivo* from human sputum and *in vitro* by Fenn's method.

Another practical feature of Fenn's work lies in the analogies he draws between organic and inorganic systems in particle flocculation, and the physiologic significance of this flocculation. Finely divided carbon, for instance, is markedly adsorptive and flocculates vigorously, while quartz can be dispersed satisfactorily and possesses but little adsorptive power in any but the colloidal state.

If, from the tendency to flocculate, the adsorptive power, and phagocytosis, it were possible to predict the lung damage from inhaling inert, insoluble particles, it would obviously be of the utmost value, and would have direct application to dusty industries and trades.

Phagocytic Dust Cells from Human Sputum

In an industrial problem involving possible lung damage from dust inhalation, I had occasion to examine a series of sputum slides prepared by Dr. Royce Paddock. The source of dust was the air of a large factory in which metal ores were crushed and dried—operations which gave rise to considerable dustiness, in spite of elaborate systems of exhaust fans and an efficient ventilation equipment.

A number of men, whose duties required intermittent exposure to widely varying dust concentrations, were examined by X-ray and showed only slightly abnormal chests, but the sputum, particularly of those men with a type of mild bronchitis, showed typical "dust cells" in large numbers.

In all such cases, mounts were prepared by Dr. Paddock by shaking the sputum with physiologic saline solution, placing a few drops on slides, fixing the cells by drying, and then washing off the salt crystals with distilled water. Slides thus prepared were mailed to this laboratory, where the cells were again fixed by methyl alcohol, mounted in purified molten dammar, and sealed with a cover slip. Occasionally mounts were stained in order to facilitate finding the cells, but, after a little practice, it was found more satisfactory to use unstained mounts, because most of the phagocytosed particles were

colored and were therefore difficult to identify in the presence of dyes. At this writing, mounts prepared more than a year ago are in good condition,

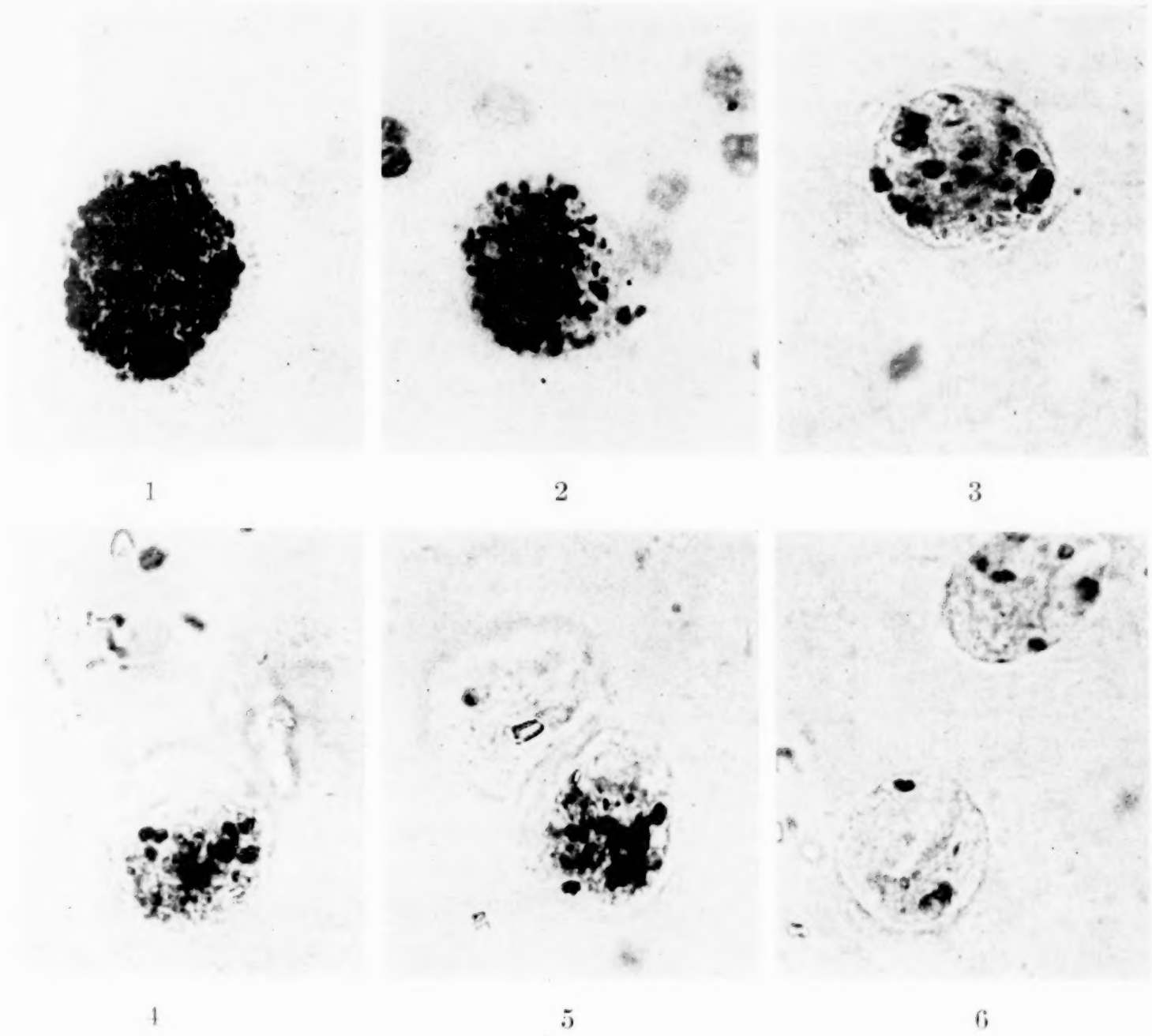

FIG. 1.—Mineral dust particles in unstained endothelial cells from human sputum. Approximately × 1500. Photographs taken by Henry Green, Research Laboratory, The New Jersey Zinc Company.

and phagocytosed particles can be measured now as readily as when the mounts were first prepared.

These dust cells are of interest both because they give an accurate idea of the size and kind of the particles which have made their way into the depths of the lungs, and also because they give a possible clue to the physiologic significance of the dust —whether or not it is dangerous.

The Measurement of the Particles

Two general methods can be used in measuring particles of the size with which we are concerned in problems of dust inhalation. The simpler of the two methods is to use a filar micrometer in the eyepiece of the microscope and actually to measure the particles by moving the micrometer adjustment from one edge of the particle to the other and reading off the distance on the vernier. This method can be used satisfactorily with all three powers of the ordinary

microscope, according to the size of the particles, and is accurate for particles as small as about 0.5 micron, but is of doubtful use for particles below that size. It is particularly suited to measuring particles in a small group the whole of which is not in focus under the high magnifications required for small particles.

The other method, advocated by Green (6) and used by him with much success, is to take a photomicrograph at a determined magnification and project the resulting image of the particles on a screen by stereopticon. By this method, a total magnification of 25,000 diameters can easily be reached, so that a particle of 1 micron will appear to be about 1 inch in diameter and can, therefore, be measured with an ordinary ruler.

The photomicrographs in Figure 1, and lantern slides from them, were made for me by Mr. Green. Although a number of particles can be seen clearly in these photographs, it is obvious that many are out of focus, simply because the cells are large in comparison (from 13 to 17 microns), are approximately spherical in shape, and have a total volume vastly greater than that of the particles. Therefore in exploring a particular cell by the projection method, a great many particles are not seen at all, and many others are out of focus. This causes errors in the size-frequency measurements, because too few particles can be measured in each photograph. Unless a great many photographs are taken, Green's method is unsatisfactory for this particular problem.

The cells in Figure 1 show that the axes of the particles point in all directions—it is a matter of chance how they happen to be fixed by the protoplasm of the cell, and it is impossible to tell whether particles are enveloped by the cell or whether they are simply lying on the surface. Furthermore, none of the particles are spherical; but to consider them as anything but spheres complicates the problem and introduces needless errors. Therefore all the measurements must be made along either the horizontal or the vertical axis, but never along both. If a large number of particles are measured, errors due to orientation of the particles will then cancel out.

Size-Frequency Distribution

In order to make clear the subsequent discussion of the size-frequency distribution of the particles, the original data are given in Table 1. These were obtained by measuring 251 particles with a filar micrometer and 2-mm. oil immersion objective. Magnifications were computed by measuring the distance between parallel lines of a known distance apart, and then converting the vernier reading of the micrometer into microns.

From the table it is seen that the first values obtained do not give a true picture of the uniformity in the size of the particles. For instance, plotting the original data gave a zigzag curve with a mode or peak at approximately $4\frac{1}{2}$ per cent. of the total particles measured, indicating very low uniformity. The first measure shows that 10 particles were 0.92 microns in diameter, 14 were 0.97, 7 were 1.02, and 14 were 1.06. It is highly improbable that any

such irregularities represent actual conditions, although two or more peaks in size-frequency curves of mixed dusts are not uncommon. It is justifiable to group the measurements in pairs by averaging, and to repeat this process one or more times until a smooth curve can be drawn. In the case of the data shown in the table, two such averages gave points from which a smooth curve (Fig. 2) could be plotted.

From a curve of this general character, the principal information desired is: (*a*) the average size of the particles, (*b*) their uniformity, and (*c*) the frequency with which the various sizes occur. A curve like that in Figure 2 gives most of this information, but in very inconvenient form. For example, the arithmetic mean of size in microns, from the data of the second averages in the table, is 1.275, a figure which corresponds to only 13.4 per cent. of the total particles measured, while the mode of the curve includes 17.8 per cent. of the particles at 1 micron. How are we to know the distribution of the rest, without going through a great many calculations? Also, is the mean value a true representative of the average-sized particle? Asymmetrical curves plotted in this manner do not answer these questions without planimetric calculations. In a symmetrical curve —that is, a curve of which the mode bisects the area under the curve—the mode, mean, and median coincide. In an asymmetrical curve, like that of Figure 2, the mode is obviously neither the mean nor the median. The mode tells us that a particular point fits the greatest number of particles of any of the possible points on the curve—it does not show the probable size of the average particle.

For plotting asymmetrical frequency curves of this general character, Hazen's (7) logarithmic probability paper is especially convenient. By this method, the logarithms of the function to be measured, in this case microns, are plotted as abscissas against the probability of occurrence as ordinates. The result is that frequency relations which are normal in their logarithms plot as straight lines, as in Figure 3. Since the line is straight, extrapolation or interpolation of any desired region is facilitated, and it is possible to estimate the relative importance of very small particles, such as those of 0.5 micron or less—particles which can be seen beneath the microscope without difficulty but of which the measurement is uncertain. In like manner, we can determine the frequency with which large particles, such as those of 5 microns, occur.

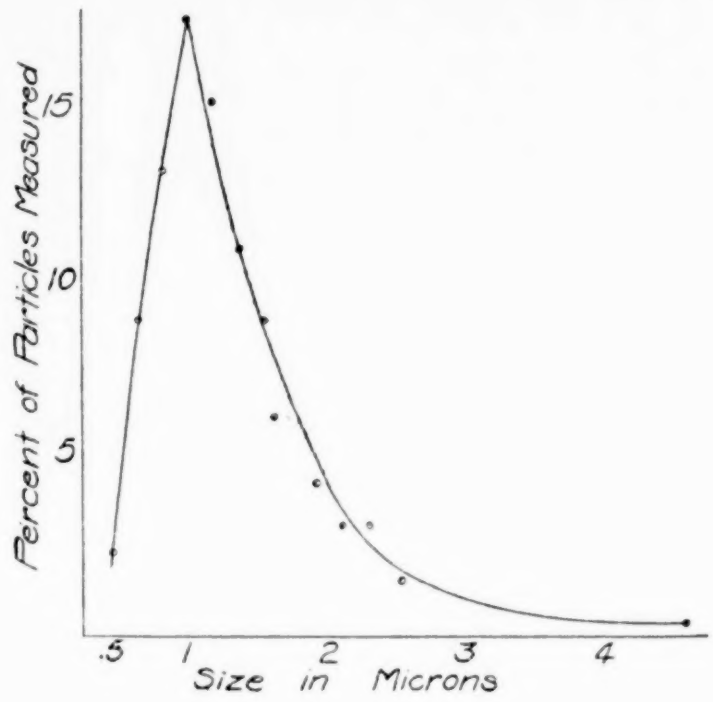

FIG. 2.—Size-frequency curve of the phagocytosed dust particles.

Another example in the applica-

TABLE 1.—SIZE-FREQUENCY MEASUREMENTS OF PHAGOCYTOSED PARTICLES

FIRST MEASURE			FIRST AVERAGE			SECOND AVERAGE		
No.	*%*	*u*	*No.*	*%*	*u*	*No.*	*%*	*u*
1	0.4	0.3	2	0.8	0.35			
1	0.4	0.4				6	2.4	0.45
1	0.4	0.46	4	1.6	0.50			
3	1.2	0.52						
2	0.8	0.56	7	2.8	0.59			
5	2.0	0.60				23	9.2	0.65
4	1.6	0.64	16	6.4	0.68			
12	4.7	0.69						
7	2.8	0.74	13	5.2	0.76			
6	2.4	0.79				34	13.4	0.82
8	3.2	0.83	21	8.4	0.86			
13	5.1	0.88						
10	4.0	0.92	24	9.6	0.95			
14	5.5	0.97				45	17.9	1.00
7	2.8	1.02	21	8.4	1.05			
14	5.5	1.06						
13	5.1	1.11	20	7.9	1.13			
7	2.8	1.16				39	15.5	1.17
8	3.2	1.20	19	7.5	1.23			
11	4.4	1.25						
5	2.0	1.30	11	4.4	1.32			
6	2.4	1.34				28	11.2	1.37
10	4.0	1.38	17	6.7	1.40			
7	2.8	1.42						
2	0.8	1.48	10	4.0	1.51			
8	3.2	1.52				23	9.2	1.55
7	2.8	1.57	13	5.1	1.60			
6	2.4	1.62						
5	2.0	1.66	10	4.0	1.68			
5	2.0	1.70				16	6.4	1.62
2	0.8	1.75	6	2.4	1.78			
4	1.6	1.80						

TABLE 1.—*Continued*

FIRST MEASURE			FIRST AVERAGE			SECOND AVERAGE		
No.	*%*	*u*	*No.*	*%*	*u*	*No.*	*%*	*u*
3	1.2	1.85	6	2.4	1.87	11	4.4	1.92
3	1.2	1.89						
2	0.8	1.94	5	2.0	1.97			
3	1.2	1.99						
3	1.2	2.03	5	2.0	2.06	8	3.2	2.11
2	0.8	2.08						
1	0.4	2.12	3	1.2	2.15			
2	0.8	2.16						
2	0.8	2.21	6	2.4	2.24	8	3.2	2.31
4	1.6	2.25						
1	0.4	2.30	2	0.8	2.33			
1	0.4	2.35						
1	0.4	2.40	2	0.8	2.42	5	2.0	2.55
1	0.4	2.44						
2	0.8	2.58	3	1.2	2.64			
1	0.4	2.67						
1	0.4	2.77	2	0.8	3.11	4	1.6	2.53
1	0.4	3.45						
1	0.4	3.50	2	0.8	3.94			
1	0.4	4.38						
1	0.4	4.60	1	0.4	4.60	1	0.4	4.60
Mean		1.296±0.0427			1.221±0.0376			1.275±0.0351
Standard Deviation		±0.6765			±0.595			±0.555
Probable Error		±0.456			±0.401			±0.374
Average Deviation		±0.432			±0.42			±0.41

tion of this system of co-ordinates is given in line B, Figure 3, and represents size-frequencies of silica particles recovered from the ashed lungs of South African miners. The data for this line were estimated from the published measurements of Watkins-Pitchford and Moir (8). It is not to be expected that the size-frequencies of these silica particles and of the phagocytosed particles (line A) should be the same; nor are the data for the silica frequencies so well established, because too few particles were measured and all silica particles had been previously digested with acids. Nevertheless, it is obvious that the frequency relation is of the

same type as that of the phagocytosed particles.

For frequency curves plotted on either arithmetic or logarithmic probability paper, the median value can be read off directly from the 50 per cent. frequency. From line A in Figure 3, the median size of the particles in microns is 1.15, with a variation of −0.028 to the left and +0.034 to the right.[1] From the original data (not the grouped data) for the curve of Figure 2, the average size was calculated to be 1.296 microns, with a variation of ±0.0427 micron (see Table 1). The median, therefore, is a better measure of the average particle than is the mean in this particular curve. If it is desired to determine the percentage of particles occurring between any special limits, the values can be read off the curve. For instance, in line A, approximately 90 − 37 = 53 per cent. of the total phagocytosed particles are between 1 and 2 microns, 2½ per cent. of the particles are less than 0.5 micron, and only 1 per cent. are greater than 3.1 microns.

In general problems of pneumonokoniosis, it is probable that the surface area of the particles is the most important dimension. It is mainly this dimension which accounts for variations in solubility and phagocytosis in any particular substance, and these factors appear to be responsible, in large part, for variations in the physiologic reactions from inhaled particulate matter.

[1] These variations apply to the accuracy of the determination of the median, not to the variation in particle size about the median.

Since the lines in Figure 3 are logarithmic in character, the dispersion of the particles, both in their surface areas and in their volumes—assuming they are spheres—can be

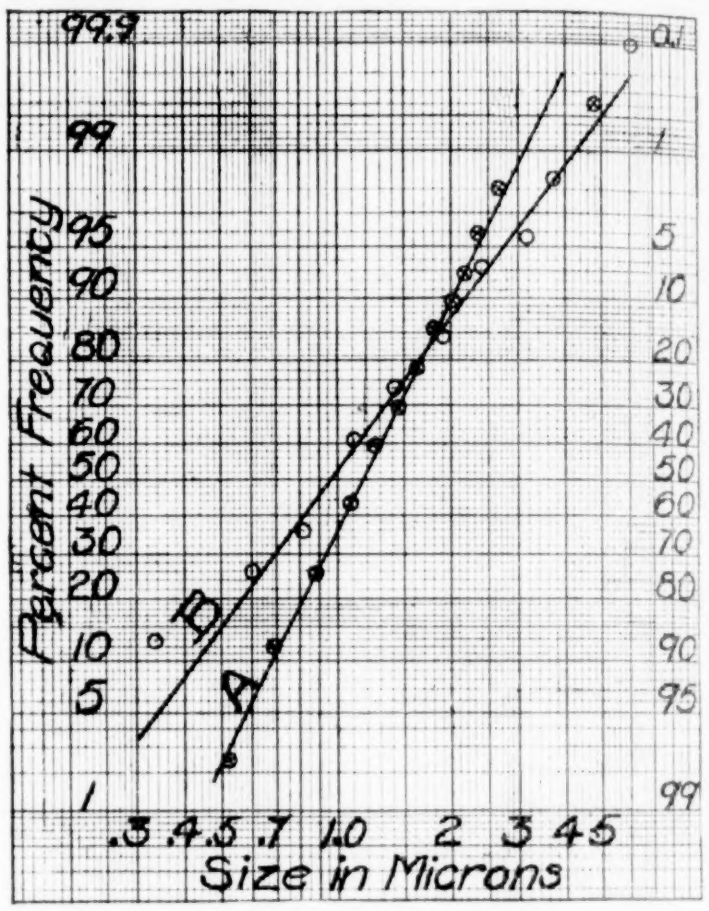

FIG. 3.—Size-frequency relations plotted on logarithmic probability paper. Line A = phagocytosed particles found in human sputum. Line B = silica particles from ashed lungs of South African miners.

calculated from the lines by multiplying by the constants πd^2 and $\pi d^3/6$ respectively.

The Identification of Phagocytosed Particles

In the case of the particles in the cells shown in Figure 1, it was necessary to distinguish between at least five different minerals, which could be identified in the dusty air the men breathed. Identification of small dust particles of the order of 0.5 to

5 microns in diameter is a vastly different problem from identifying particles of 20 to 40 microns, such as the petrologist studies. Furthermore, the particles must be examined *in situ*, which renders the problem still more complicated. The petrologist and pigment microscopist can prepare samples in media of different refractive indices, and often identify particles by finding in which medium they disappear; they can measure their angles of cleavage, and note their appearance or color to assist in their identification. In the dust cells, very few particles over 3 microns are found, and all of them are more or less imbedded in the cell. Consequently, their identification by the petrologist's methods is both uncertain and unsatisfactory.

The five minerals comprising most of these particular dusts could all be distinguished in preparations of the pure minerals, ground into sizes comparable to those found in the cells. One mineral, willemite, fluoresced under ultraviolet light, so that, from mounts prepared on quartz slides, willemite could be detected under the ultraviolet microscope. Under visible light, it was transparent and colorless, and gave no useful distinguishing features in sizes less than 3 or 4 microns. Another of the five, franklinite, was insoluble in hot mineral acids, was of purple color, and magnetic. A third, zincite, was soluble without effervescence, was of orange color, and particularly easy to identify under dark-ground illumination. A fourth, rhodonite, was transparent, colorless, and difficultly soluble in hot or cold acids; while the fifth, limestone (mainly calcite), was colorless and soluble with effervescence in weak mineral acids.

Of these five minerals, franklinite occurred in the cells oftenest, while zincite was the next most frequent. Both of these are of a deep orange to purple color, and easily distinguished from willemite, rhodonite, and calcite, all of which are colorless in the small-sized particles contained in the cells. Although the colorless minerals were found occasionally in the cells, the colored particles were in great excess over the colorless. Fenn (3) found that manganese silicate, which is colorless in small particles and is probably the same rhodonite as that under discussion, was taken up by phagocytes some twenty times less readily than manganese dioxide; so that it is not surprising to find rhodonite rarely in human dust cells. Calcite and willemite were not identified in the dust cells, although the cell examinations were not extensive enough to warrant saying that these minerals never occurred.

Composition of the Dust in the Air

The fact that the dark-colored minerals are in excess in the cells is not of itself proof of selective phagocytosis. It is necessary to determine the proportions of the different minerals in the air inhaled. This was done by several different methods.

In the plant in which this dust problem arose, a large quantity of ore is recovered by the exhaust fan system, and is necessarily composed of particles small enough to be carried by air currents along considerable lengths of narrow pipe. An average

of the dust samples, collected over the year previous to our investigation, gave the following figures:

	Per Cent.
Zn	13.4
Fe	11.9
Mn	6.9
CaO	20.6
SiO_2	10.4

Dust which had settled out on rafters, floors, covers of machinery, and like places, was sampled by us in various parts of the plant, and gave the following figures:

	Per Cent.
SiO_2	8.88
MnO	11.24
Fe_2O_3	12.65
FeO	0.96
$CaCO_3$	39.92
CaO	1.64
ZnS	1.03
ZnO	14.31
Al_2O_3	1.21
$MgCO_3$	6.79
Mn_2O_3	(trace)
Loss on ignition	1.10
PbO	0.059
	99.789
H_2O at 110°C	0.29

Converting these figures into zinc, iron, manganese, etc., gives:

	Per Cent.
Zn	12.2
Fe	9.7
Mn	8.7
CaO	24.0
SiO_2	8.9

These figures compare favorably with the yearly average of analyses from the collected dusts. Closer agreement would probably be a matter of chance, as the composition of the ore, and therefore of the dust in the air, is variable.

At the time this study was made, numerous samples of dust were collected from the air of the factory by electric precipitator (9) and by Owens' counter (10). Both methods give samples well adapted to microscopic examination, especially so since neither requires the wetting of the dust caught. From representative samples taken from the air of the factory, together with samples of the rafter dust and dust collected by the exhaust system of ventilation, it was found that about 42 per cent. of the particles were dark or opaque (franklinite and zincite) and that 58 per cent. were light or transparent (calcite, willemite, and rhodonite).

From the analyses of the rafter dust, it is reasonable to assume that the calcium carbonate, 39.92 per cent., is present as calcite and is therefore colorless, and that the silica (SiO_2) is combined with zinc oxide or manganous oxide to form colorless particles of willemite or rhodonite.[2] If these assumptions are correct, approximately 62 per cent. of the total dust particles in the air breathed by the men would be colorless and the remainder colored. One constituent of the rafter dust, magnesium carbonate, we have ignored. While this was not identified as such, it is probable that it should be added to the colorless particles, and their total would thus be increased.

In any event, it is obvious that the colored particles are in a decided minority in the air, but far in excess in the dust cells from human sputum. From this it follows that of the five

[2] SiO_2 present as free silica was too slight to be considered.

minerals in question, franklinite and zincite are the easiest to remove from the lung area by phagocytosis; willemite and rhodonite tend to remain; while calcite we accepted as comparatively harmless, although it was not found in the dust cells.

The fact that calcite is present in the inhaled dust in such decided excess, but is not found in the dust cells, can only be accounted for by solubility. In their discussion of the mechanism of the removal of manganese dioxide and silicate from blood and body fluids, Drinker, Shaw, and Drinker (11) have shown the importance of solubility. Gardner and Dworski (12) found that marble dust (calcium carbonate) was removed from the lungs of guinea-pigs by solution both before and after phagocytosis. It is probable, therefore, that the cycle of events in the present problem is represented by the disappearance of particles like calcium and magnesium carbonates, either before or after phagocytosis, followed by the appearance in the endothelial cell of the sputum of the more refractory particles like rhodonite, willemite, zincite, and franklinite.

Definite proof of selective lung damage by these dusts can only be reached by direct postmortem examinations. At this writing, the opportunity for such examinations has not been obtained.

Summary

From the size measurement of phagocytosed dusts and their approximate frequency of occurrence in endothelial cells from sputum of men exposed to dusty air, an attempt is made to predict the relative power of certain dust particles to produce pneumonokoniosis.

From a comparison of dust inhaled, as sampled by electric precipitator, and dust in the cells from human sputum, selective phagocytosis is indicated.

The median size of the phagocytosed particles was found to be 1.15 microns in diameter and the mean 1.275 microns, in cells whose diameter varied from about 13 to 17 microns. The size-frequency curve of the phagocytosed particles is shown to be asymmetrical, and plots as a straight line on Hazen's logarithmic probability paper. Photomicrographs of the dust cells and the size-frequency curve of the phagocytosed particles are given, with details of the methods used in measuring the particles and determining their size-frequency distribution.

I am indebted to Prof. E. B. Wilson and Dr. C. R. Doering of this School for their helpful suggestions and criticisms on the statistical portion of this paper.

BIBLIOGRAPHY

1. Mavrogordato, A.: The Value of the Konimeter—Being an Investigation into the Methods and Results of Dust-Sampling as at Present Practised in the Mines of the Witwatersrand. So. African Inst. Med. Res., Pub. No. 17, p. 14. Johannesburg, Aug., 1923.

2. Fenn, W. O.: The Phagocytosis of Solid Particles: I. Quartz. Jour. Gen. Physiol., 1921, *3*, 439; II. Carbon. *Ibid.*, p. 465.
3. Fenn, W. O.: The Phagocytosis of Solid Particles: III. Carbon and Quartz. *Ibid.*, p. 575.
4. Haldane, J. S.: Effects of Mine-Dust Inhalation. Engin. and Min. Jour., 1918, *106*, 475.
5. Mavrogordato, A.: Experiments on the Effects of Dust Inhalations. Jour. Hyg., 1918, *17*, 439.
6. Green, H.: A Photomicrographic Method for the Determination of Particle Size of Paint and Rubber Pigments. Jour. Franklin Inst., 1921, *192*, 637.
7. Whipple, G. C.: Vital Statistics. New York, John Wiley & Sons, Inc., 1923, p. 451.
8. Watkins-Pitchford, W., and Moir, J.: On the Nature of the Doubly Refracting Particles Seen in Microscopic Sections of Silicotic Lungs and an Improved Method for Disclosing Siliceous Particles in Such Sections. So. African Inst. Med. Res., Pub. No. 7. Johannesburg, Sept., 1916.
9. Drinker, P., Thomson, R. M., and Fitchet, S. M.: Atmospheric Particulate Matter: II. The Use of Electric Precipitation for Quantitative Determinations and Microscopy. This Jour., 1923–1924, *5*, 162.
10. Owens, J. S.: Jet Dust Counting Apparatus. This Jour., 1922–1923, *4*, 522.
11. Drinker, C. K., Shaw, L. A., and Drinker, K. R.: The Deposition and Subsequent Course of Particulate Material (Manganese Dioxide and Manganese Meta-Silicate) Administered Intravenously to Cats and to Rabbits. Jour. Exper. Med., 1923, *37*, 829.
12. Gardner, L. U., and Dworski, M.: Studies on the Relation of Mineral Dusts to Tuberculosis: II. The Relatively Early Lesions Produced by the Inhalation of Marble Dust and their Influence on Pulmonary Tuberculosis. Am. Rev. Tuberc., 1922–1923, *6*, 782.

THE EFFECT OF ATMOSPHERIC CONDITIONS ON HEALTH AND EFFICIENCY (WITH SPECIAL REFERENCE TO THE COTTON INDUSTRY)*

S. WYATT, M.Sc.

Investigator to the Industrial Fatigue Research Board, London

CONTENTS

	PAGE
General Considerations	317
Effect of Unsuitable Atmospheric Conditions	319
Existing Conditions in Weaving Sheds	324
Effect on Health and Efficiency	326
Possible Improvements	330
Future Possibilities	338
Summary	342

GENERAL CONSIDERATIONS

THE human body is a mechanism which is constantly producing and losing heat. Under normal conditions of existence the healthy body is maintained at a fairly uniform temperature (about 98°F.), which means that the rate of heat production is balanced by the rate of heat loss. Heat is lost from the body by the processes of radiation, convection, and evaporation; consequently anything which interferes with the functioning of these processes will obstruct the flow of heat from the body.

The loss of heat by radiation is dependent on the difference between the temperature of the skin and that of the surrounding air. Thus an increase in the temperature of the air is accompanied by a reduction in the flow of radiant heat from the body. When the temperature of the air is 68°F., for instance, the rate of heat loss from the body by radiation is approximately 140 per cent. more than when the temperature is 86°F. (1). When the temperature of the environment equals that of the body, the loss of heat by radiation ceases; consequently this factor as a means of dissipating body heat is of minor importance in high atmospheric temperatures. It must nevertheless be taken into account when considering the most suitable atmospheric conditions for industrial operatives.

The loss of heat by convection is produced by the movement and removal of the air in contact with the body. Heat from the body passes by conduction to the adjoining air, which, in turn, has its temperature raised. Unless this heated air is removed and replaced by a cooler stream, the flow of heat from the body is greatly retarded. The more rapidly the air in contact with the skin is renewed, the greater is the amount of heat conducted away from the body and the less is the tendency for the body to become overheated. Thus the rate of movement of the air in the vicinity of the body is another important factor in the maintenance of a suitable body temperature.

*Received for publication Jan. 23, 1925.

The loss of heat by evaporation depends on the amount of water vapor in the surrounding air. When the air contains little vapor, the rate of evaporation of moisture on the surface of the body is rapid, but decreases as the amount of vapor in the air increases. This does not mean that evaporation from the body ceases when the adjoining atmosphere is saturated with vapor. This condition would exist only when the surrounding air is saturated and at the same temperature as the body. As a rule the temperature of the body is higher than that of the surrounding air, and although the latter may be saturated with water vapor (*i.e.*, its *relative* humidity be 100 per cent.), when heated by contact with the body, it is capable of holding still more moisture. Thus saturated air at 60°F. contains only 5.8 grains of water vapor per cubic foot, but when raised to body temperature the same volume is capable of holding 18.7 grains. The rate of evaporation of moisture from the skin does not, therefore, depend on the relative humidity of the surrounding air, but on the absolute amount of water vapor it contains, that is to say on the difference between the absolute amount of moisture in the atmosphere and the amount capable of being taken up by the air when warmed up to the lung and skin temperatures.

The conversion of superficial body moisture into water vapor absorbs a considerable quantity of heat from the body; and the more rapid the rate of evaporation, the greater is the amount of body heat so absorbed. Evaporation of this kind, therefore, has a cooling effect on the body, and this property makes the process of evaporation another important factor in the preservation of an equable body temperature.

Unless the air in contact with the body is constantly removed and renewed, it tends to become heated to body temperature and saturated with water vapor from the body at that temperature. Under such conditions the rate of evaporation is greatly retarded and the consequent cooling effect is considerably reduced. Movement of the air in the vicinity of the body will accordingly facilitate evaporation, and by so doing increase the flow of heat from the body. Air movement thus has a double effect; it not only promotes the loss of heat by convection when the body is comparatively dry, but also increases the cooling effect due to evaporation when the body is moist.

In addition to the foregoing factors, the loss of heat from the body is also dependent on the nature and amount of clothing worn. If, for instance, the radiant heat emitted from the naked skin in a room at 59°F. is taken as 100, it is reduced by (2):

a wool vest to 73
a wool vest and linen shirt to 60
a wool vest, linen shirt, and waistcoat to 46

Further, a close cotton mesh restricts the loss of heat much more than closely woven cotton, and a knitted woolen fabric is still worse (2, p. 239). The properties of a garment have been found to depend almost wholly on the manner of its weaving, and not on the kind of material used. Thus Flack and Hill (2, p. 244) state that "it made little difference whether the shirt was cellular cotton or flannelette or

flannel, the protection from cooling depending on the restriction of ventilation, not on the nature of the material." In a stagnant atmosphere the air in the meshes of the clothing and

TABLE 1.—INCREASE IN THE AMOUNT OF HEAT PRODUCED BY DIFFERENT ACTIVITIES[1]

OCCUPATION	ADDITIONAL CALORIES	INCREASE
		%
Tailor	44	57.1
Shoemaker	90	116.9
Metal worker	141	183.1
Stonemason	300	389.6

[1] These figures are on the high side, as the subjects did their best throughout the tests, which were not of long duration.

between the clothing and the surface of the body tends to approximate the body temperature and to become saturated with moisture. In this respect it resembles the atmosphere of a moist tropical climate, and considerably retards the rate of heat loss from the body. The kind and amount of clothing worn is, then, another important factor in promoting or retarding the loss of heat from the body.

Lastly, the preservation of a suitable body temperature is also dependent on the amount of activity performed. The amount of heat produced in the body increases considerably as the form of activity becomes more strenuous, and unless the rate of heat loss is also increased, there will be an accumulation of heat in the body. A resting man, for instance, produces about 77 calories an hour, but this amount is increased during activity. The figures given in Table 1 show the extent of the increase observed in different masculine occupations (1, p. 54).

It follows, therefore, that as the intensity of the activity increases, a correspondingly greater amount of heat must be dissipated by the body if a rise in body temperature is to be avoided. This means that greater demands must be made on the processes of radiation, convection, and evaporation, and the conditions of the atmosphere which promote their efficient functioning become increasingly important.

Effect of Unsuitable Atmospheric Conditions

Under pleasant atmospheric conditions the skin remains comparatively dry, and the processes of radiation and convection are responsible for most of the heat lost by the body. During periods of bodily exertion, or under unfavorable atmospheric conditions, these processes are unable to maintain an adequate flow of heat from the body, with the result that the evaporative mechanism comes into play. The skin becomes covered with visible perspiration, the evaporation of which assists considerably in the cooling of the body.

High Atmospheric Temperatures

Overheating of the body increases the activity of the heart, which has to send an ever-increasing quantity of blood to the skin to be cooled there, in addition to keeping up the supply necessary for the use of the brain and the muscles. If the heart becomes fatigued, the supply of blood, and so of oxygen, to these organs is diminished

and working capacity in consequence decreased (1, p. 60). The frequency of the pulse rises greatly with undercooling of the body. "A warm skin, (produced by inadequate heat loss) diminishes the tone of the muscles, lowers the exchange of material in the body, and depresses the appetite; the natural tendency is for the nervous system to become less active, and for muscular work to be diminished" (3). A cool skin, on the other hand, promotes activity in order to maintain warmth, increases the efficiency of blood circulation, aids digestion, and consequently improves the general health and fitness of the individual. Thus unsuitable atmospheric conditions are undesirable from the physiologic standpoint, and have a depressing effect on the inclination to work and the capacity to perform work. "Every hindrance to heat loss," says Rubner, "either reduces bodily exertion or causes the exertion to be done under a feeling of oppression and a burden of weariness. Therefore the production of sweating must be energetically countered by adequate conditions of environment (1, p. 59). The debilitating effect of a monotonous, humid, warm climate, such as that of Singapore, is beyond dispute; so, too, is the health giving effect of exposure to open air and sunshine in children's sanatoria and open-air schools.

The retarding effect of a high temperature on the flow of heat from the body may be observed on a calm, hot day in summer, when the small difference in temperature between the body and the surrounding air produces sweating even when the individual is only slightly active. Exposure to high temperatures under industrial conditions will have a similar effect and will tend to produce discomfort and reduce efficiency. Vernon (4), for instance, found that the output of tin-plate millmen was lowest during the hottest months of the year, and, in general, varied inversely with the temperature. In the manufacture of cycle chains, during a hot period when the average temperature was 80°F., the output was 13 per cent. less than on days having an average temperature of 68°F. (5).

The New York Commission on Ventilation (6) found that atmospheric temperature had a marked and significant influence on the performance of physical work. An increase in room temperature from 68°F. to 75°F. caused a decrease of 15 per cent. in the physical work performed by men who were not compelled to work with maximum effort but were stimulated by a cash bonus; and an increase from 68°F. to 86°F. with a relative humidity of 80 per cent. caused a decrease of 28 per cent. in the physical work performed under conditions of maximal efforts. The same Commission also found that, in mental work, feelings of comfort were approximately the same whether the temperature was 68°F. or 75°F., but a temperature of 86°F. with a relative humidity of 80 per cent. was distinctly uncomfortable. Under these different atmospheric conditions, however, the quantity or quality of output, as indicated by psychologic tests, was approximately the same in all cases. Since the tests were of short duration (a few minutes in each case), the effect of interest and volitional effort may have had a significant influence on the results.

The effect of temperature on health has been investigated by Vernon and Rusher (7) in connection with the iron and steel industry. They found that the greatest amount of sickness occurred among workers who were exposed to the highest temperatures, and generally decreased progressively as the temperature approached normal. The examples mentioned serve to illustrate the effect of high atmospheric temperatures on working activity, and indicate the importance of temperature as a factor in the regulation of the quantity of heat lost by the body.

Air Movement

The influence of air movement on bodily comfort and efficiency is often noticeable in everyday situations. Everyone is familiar with the stifling nature of the atmosphere on a hot, muggy day in summer, and the relief obtained by a ride in an open tram or car. A similar effect is experienced in restaurants and theaters when a fan is suddenly set in motion. In these examples, the only difference in the atmospheric conditions is the artificially produced air movement. In a warm, stagnant atmosphere, the air in contact with the body and that confined in the clothing becomes heated and saturated with moisture from the body. Most of the air in contact with the skin is accordingly hot and moist, and retards the flow of heat from the body. The individual begins to feel overheated, discomfort increases, and the inclination to activity is reduced. Air in motion removes the hot, moist air from the vicinity of the body, promotes the evaporation of superficial moisture, thereby cooling the skin and stimulating bodily activity. The effect of air movement on the rate of cooling of a large-bulbed thermometer at body temperature is shown by the figures

TABLE 2.—EFFECT OF AIR MOVEMENT ON THE RATE OF COOLING OF A LARGE-BULBED THERMOMETER

TEMPERATURE	AIR MOVING AT RATE OF (*mi. per hr.*)				STILL AIR
	20	8.8	2.2	1.1	
°F.	*millicalories per square centimeter per second*				
50	45.0	33.1	20.1	16.4	7.1
68	28.1	20.6	12.5	10.3	4.4
86	11.2	8.1	4.9	4.0	1.7

given in Table 2 (1, p. 51). Thus when the temperature remains the same (horizontal results), the loss of heat increases as the air velocity increases; but when the temperature rises (vertical results), the same air velocity has a reduced effect on the rate of heat loss. A given increase in the rate of air movement at low velocities has also been demonstrated to have a greater cooling effect than a similar increase at high velocities, as shown in the curves in Figure 1. Points lying along the same line represent conditions of equal comfort for a constant relative humidity of 80 per cent. When the initial temperature is 50°F., for instance, an increase in the rate of air movement from 0 to 100 feet per minute will have a cooling effect which is equivalent to a reduction in temperature of 10°F. In other words, a temperature of 60° (point B) with an air velocity of 100 feet per minute will be just as comfortable as a temperature of 50° (point A) with

no air movement. From the same curve it will be seen that an increase in the air velocity from 400 to 500 feet per minute is equivalent to a reduction in temperature of only 1.3°F.

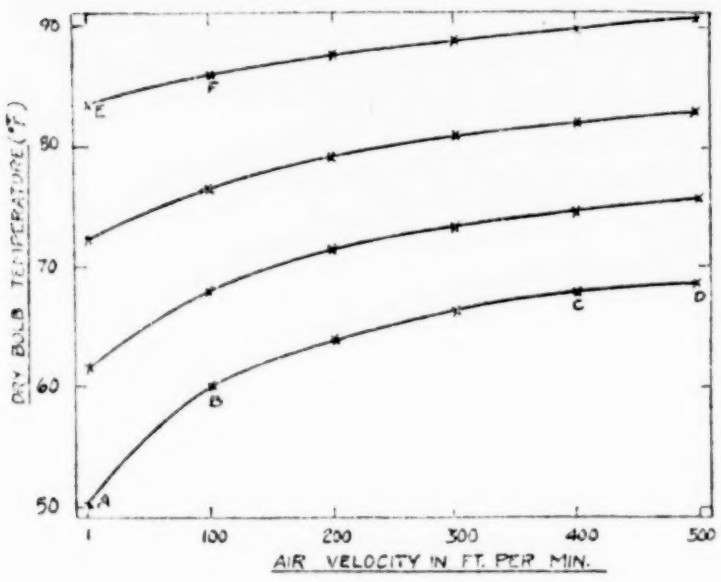

FIG. 1.—Effect of different air velocities on dry bulb temperature for a constant relative humidity of 80 per cent.

That is, a temperature of 67.3° (point D) with an air velocity of 500 feet per minute will give the same feelings of comfort as a temperature of 66°F. (point C) with an air velocity of 400 feet per minute. This fact is important, since comparatively low air velocities are more likely to be tolerated and more easily produced than air velocities of 400 to 500 feet per minute.

On the other hand, the curves also show that as the temperature rises, the cooling effect of increased air movement at low velocities progressively decreases. As mentioned above, with an initial temperature of 50°F. an increase in the rate of air movement from 0 to 100 feet per minute is equivalent to a reduction in temperature of 10°F.; but when the initial temperature is 83.5°F. (point E), the same increase in air velocity will only produce a reduction in temperature equivalent to 2.5°F. (point F) (8). Haldane (9) found that the endurable limit of temperature (wet bulb) is about 88°F. if no work is being done, while it is 78°F. if a moderate amount of mechanical work is done. With an air current of 150 feet per minute, the endurable limits are raised to 93°F. and 85°F. respectively.

Increased air movement has also been demonstrated (10) to have a most beneficial effect in the case of natives working in deep South African gold mines. For instance, a small fan, with a capacity of about 2,000 cubic feet of air per minute, placed at a distance of 15 feet from the worker, increased his output by 46 per cent. In a study on the physiologic effects of high temperatures and humidities in metal mines (11), it was found that, in a still atmosphere of 80°F. to 90°F., manual labor caused the body temperature to rise in a short period to 102°F. and frequently to 103°F. when the relative humidity exceeded 95 per cent. With air velocities varying between 400 and 500 feet per minute, there was no marked change in body temperature or pulse rate, and no appreciable discomfort was experienced.

Additional results obtained by Lewis (12) show the effect of increasing the velocity of the air in mines. The conditions observed are given in Table 3. The effect of unsuitable atmospheric conditions can, then, be mitigated to a large extent by increasing the rate of air movement in the vicinity of the operatives, but, as the temperature rises, a much greater air velocity is necessary to produce the same favorable effects.

The dependence of bodily comfort and efficiency on the amount of water

vapor in the air is illustrated by the difference in feelings and inclination to activity on a warm, dry day, when one feels much more comfortable and energetic than on a day when the

TABLE 3.—EFFECT OF INCREASED AIR MOVEMENT IN MINES

DRY BULB	WET BULB	AIR VELOCITY	REMARKS OF WORKERS
°F.	°F.	ft. per min.	
88.7	88.0	0	Unendurable.
88.0	84.7	360	Good for work.
87.0	83.0	710	Excessive velocity.
81.4	80.2	0	Oppressive.
80.2	78.6	770	Excessive velocity.

conditions are damp but otherwise similar. The enervating effect of some of our seaside resorts is largely due to the quantity of moisture contained in the air in those places. In a hot, moist, and stagnant atmosphere, the body loses heat almost entirely by means of the evaporation of superficial moisture, and the cooling effect is accordingly largely dependent on the amount of water vapor in the surrounding air. The rate of heat loss from a damp, large-bulbed thermometer at body temperature has been shown by Vernon (13) to depend only on the wet bulb temperature, and to be independent of the dry bulb temperature. Even when the surrounding air was practically saturated with moisture the effect was still the same. This is because the cooler, though saturated, air in the vicinity of the body, when heated by the skin to body temperature, is capable of absorbing a greater quantity of water vapor. Thus, saturated air at 70°F. when raised to body temperature has its capacity for absorbing water vapor increased approximately one and a half times. Similarly air at body temperature is capable of containing 76 per cent. more water vapor than air at 80°F. (1, p. 99). Haldane also showed (14) that the maximum temperature which can be endured depends only on the wet bulb temperature, and not at all on the dry bulb or relative humidity. The same writer also states that at a wet bulb temperature of about 80°F. the actual amount of work done by a miner begins to fall off, and as the wet bulb rises still further the work done gradually diminishes to the vanishing point.

"There are hot moist mines where the day's working power of the white is reduced by the strain on his heat-losing mechanism to no more than the equivalent of two hours' labour performed out of doors" (1, p. 56). In humid weaving sheds, the artificial methods of humidification increase the amount of moisture in the shed atmosphere, and there is medical evidence to show that a rise in mouth temperature is observed when the temperature of the wet bulb exceeds 75°F. and that when such is the case, the weavers are likely to be working under adverse physiologic conditions (15). Thus when the temperature is high, the amount of water vapor in the air has an important influence on health and efficiency, and must be seriously considered when attempting to ameliorate the unfavorable effects of unsuitable atmospheric conditions.

Existing Conditions in Weaving Sheds

Throughout the weaving section of the cotton industry, the sheds are usually kept at a temperature well

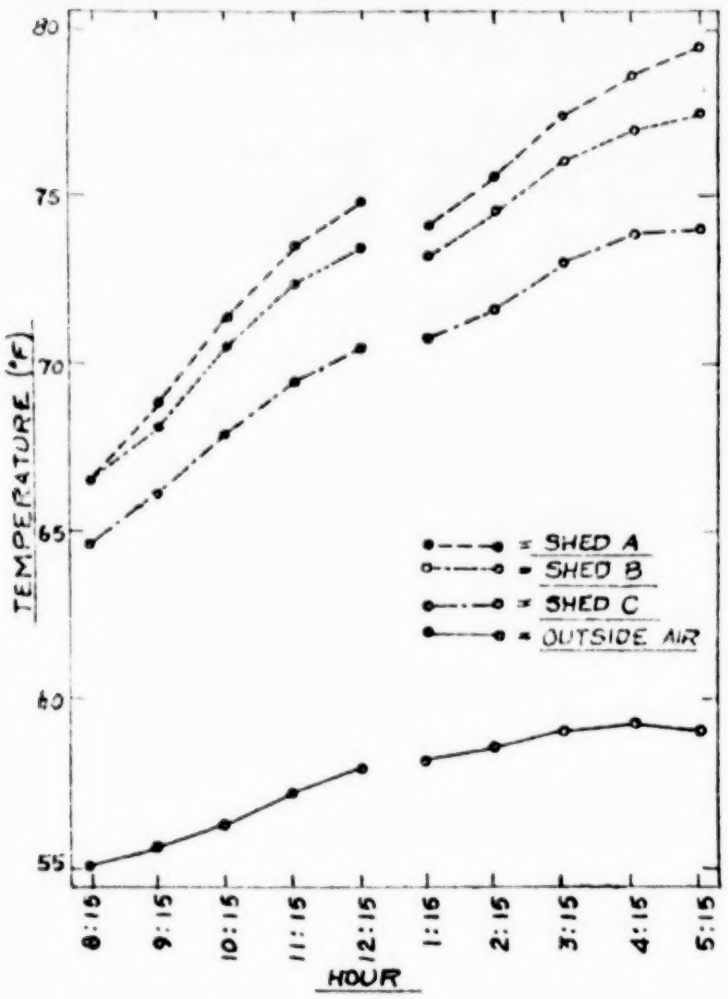

Fig. 2.—Hourly variations in temperature during August, 1920, in different sheds.

above 60°F., and in many cases the average temperature for the year is from 70°F. to 75°F. During the hot summer months the shed temperature frequently reaches 85°F. to 90°F., hence under such conditions the cooling effect of the air in the shed is greatly reduced, and the operatives are affected accordingly. In addition to the seasonal variations in temperature, there is also the gradual rise in temperature throughout the day. This is illustrated in the curves in Figure 2 which represent the hourly variations in temperature during the month of August, 1920, in different sheds. The differences between the temperature of the sheds and that of the outside air show the extent to which the sheds are heated while work is in progress. The curves show that

TABLE 4.—OBSERVED RATE OF AIR MOVEMENT IN HUMID WEAVING SHEDS

SHED	AIR MOVEMENT
	ft. per min.
A	26
B	19
C	17
D	30
E	13
F	18
G	18
H	41
I	23
J	24
K	24
L	19
M	39
N	18
O	27

the operatives are exposed to increasingly unfavorable atmospheric temperatures as the day advances, and if a temperature of 60°F. to 65°F. is accepted as the most suitable for the bodily comfort and activity of the weavers, then a gradually increasing strain is thrown on their heat regulating mechanism as work proceeds throughout the day. At the same time, the daily rise in temperature will have a favorable effect on the yarn used in the manufacturing process, in so far as it facilitates weaving by causing a reduction in the number of yarn breakages.

The rate of air movement in weaving sheds is, on the average, about 24 feet per minute. Observations made in

different positions at different times of the day in fifteen sheds gave the average results shown in Table 4. These rates are quite imperceptible, and have very little effect in promoting the dissipation of heat from the bodies of the operatives. They vary slightly, of course, in different parts of the same shed, and are greater in some sheds than in others, but in general, the air in all weaving sheds is comparatively stagnant. For comparative purposes, it may be stated that on a bright, pleasant day outside, with a dry bulb temperature of 68°F. and a wet bulb of 60°F. the rate of air movement is about 80 feet per minute. With the higher temperatures observed in weaving sheds a much higher rate of air movement is necessary if an adequate cooling power is to be obtained.

The third factor in the preservation of bodily comfort and efficiency (*viz.*, the amount of water vapor in the air as indicated by the wet bulb temperature) is of great importance in artificially humidified sheds. In such sheds the amount of moisture in the air usually approaches the legal limits. This means that the wet bulb temperature is usually only 2°F. below the dry bulb (up to a temperature of 70°F.), after which the difference progressively increases until a wet bulb of 75°F. is reached, when the further introduction of moisture is prohibited. The period of time spent at and above different wet bulb temperatures in cotton weaving sheds during 1906 is given in Table 5 (15, p. 43). These figures are equivalent to saying that a weaver spent, on the average, 21 per cent. of his time, or about sixty-five days, at a wet bulb temperature of 70°F. or over; 6.5 per cent., or about twenty days, at 74°F. or over; 2.8 per cent., or about eight and a half days, at 76°F. or over. The above results, however, are averages,

TABLE 5.—PERCENTAGE OF TIME SPENT AT DIFFERENT WET BULB TEMPERATURES IN HUMID WEAVING SHEDS (1906)

WET BULB TEMPERATURE	PERCENTAGE OF TIME
70° and over	21.1
74° and over	6.51
76° and over	2.84
78° and over	0.98
80° and over	0.30

and fail to show the actual conditions in individual sheds. For instance, some figures obtained in six sheds during the summer of 1910 show that these sheds had eighty-four hours, and in August seventy-six hours, with a wet bulb over 75°F. In one of these sheds during the month of July, a wet bulb temperature of 75°F. was exceeded in 166 hours out of a total working time of 244 hours. In general, the observations in the sheds in question showed that for three-fourths of the total working time in summer the wet bulb temperature exceeded 70°F. and for one-fourth of the time it was above 75°F. Thus for a considerable part of the summer months, the operatives in humid weaving sheds are exposed to atmospheric conditions which are very different from those which are usually found in the outside air. The air in the sheds is warm and almost saturated with moisture, and in addition is comparatively stagnant. It is important to ascertain the

effect of such conditions on the health and efficiency of the operatives.

Effect on Health and Efficiency

In humid weaving sheds, efficiency increases (due to fewer yarn breakages) as the temperature and relative humidity increase. In a weaving investigation (16) it was found, for instance, that in one shed with a temperature of 77°F. and a relative humidity of 85 per cent. the breakages were few. With the same temperature, but with a relative humidity of 63.4 per cent., the weavers complained of the cloth weaving badly. "Ends" were continually breaking out, and the operatives said this was due to the fact that the steam was turned off earlier in the day. In the former case the efficiency was 76.5 per cent., but in the latter it was only 68.9 per cent.

In the same investigation, the humidifying apparatus in one of the sheds broke down, and the efficiency obtained during the afternoon when the humidifier was not in use was 77.6 per cent., compared with an efficiency of 82.4 per cent. on the previous afternoon when the humidifier was working. On the day of lower output the ends were "flying out" in all directions and although the weavers tried to cope with the unusual conditions, some of them ultimately gave up the attempt.

In another inquiry (15, pp. 1 to 11), a series of experiments was carried out by certain manufacturers with the object of determining the effects of different degrees of humidity on weaving efficiency. The results of these experiments are summarized in Table 6 and show that the number of breakages increased as the relative humidity decreased, and that in the sheds in question a high temperature, if unaccompanied by a high relative humidity, did not suffice to maintain weaving efficiency.

The relation between unsuitable atmospheric conditions and human effici-

TABLE 6.—RELATION BETWEEN HUMIDITY AND YARN BREAKAGES

SHED	TEMPERATURE		RELATIVE HUMIDITY	REMARKS
	Dry Bulb	Wet Bulb		
	°F.	°F.	%	
X	80–92	75	75–41	Repeated complaints from weavers. Feel of cloth absolutely spoilt. Breakages very heavy, an increase of 62 per cent. on the average.
Y	a 78.4	74.2	78.4	Average number of warp breakages = 6.2.
	b 79.3	72.8	69.0	" " " " " = 12.8.
Z	a 77.5	73.5	79.0	Weaving "all right."
	b 79.0	72.0	67.0	Weaving gradually growing worse.
	c 81.0	73.5	66.0	Weaving at a standstill. Twist breaking out in bunches.

ency has also been considered by different investigators, and a certain amount of evidence obtained. As the result of an extensive inquiry into the conditions of work in the weaving section of the cotton industry a greater decrease in efficiency was found in summer toward the end of the spell of work than in winter (16, p. 40). This feature of the results is shown in the curves in Figure 3. Further, when the temperature is high, efficiency decreases fairly rapidly throughout the spell; but with lower temperatures, output is maintained at a fairly high level as work proceeds. This tendency is illustrated in the curves in Figure 4. Thus, although the yarn in humid sheds is favorably affected by an increase in temperature or humidity, the actual efficiency of production does not continue to increase indefinitely as the temperature or humidity increases. The number of yarn breakages may continue to decrease, but the ability of the operative to attend to these breakages is reduced. In another case (16, p. 41), when the temperature was 76.5°F. and the relative humidity 85 per cent., the operatives complained about the heat, and frequently asked about the temperature. When the temperature was 71.7°F. and the humidity 86 per cent., the conditions were considered fairly satisfactory. In the former case the efficiency was 76.5 per cent., but in the latter it was 78.2 per cent., although the number of yarn breakages was presumably greater. Thus, atmospheric conditions which are best for the warp are unsuitable for the weaver. Under existing regulations, the best conditions for productive efficiency in humid weaving sheds seem to be obtained with a dry bulb temperature of 70°F. to 75°F. and a relative humidity of 80 to 85 per cent.

A similar state of affairs was observed by Weston (17) in the linen

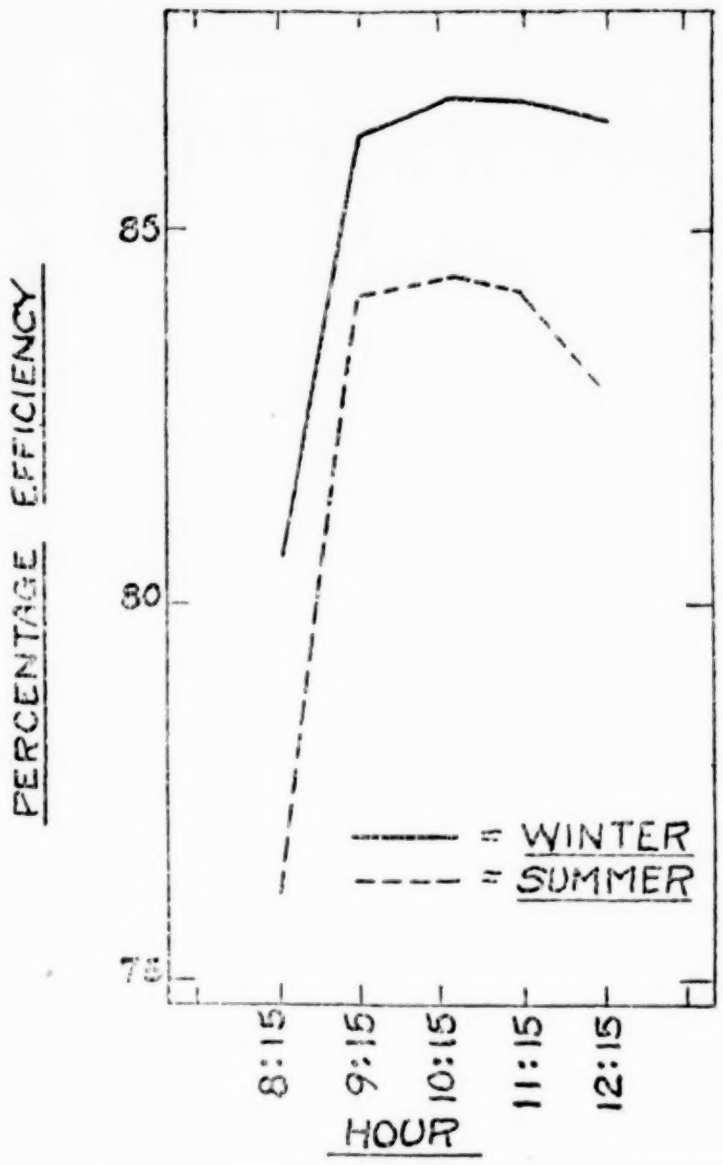

FIG. 3.—Hourly variations in efficiency in summer and winter (morning spells).

industry. He concludes that the economic limit of temperature for fine linen weaving is reached when the wet bulb temperature exceeds 73°F. Up to this limit, increase of temperature results in increase of productive efficiency, but beyond it efficiency falls, owing to the discomfort and fatigue of the weavers.

Work in humid weaving sheds has also been asserted to be detrimental to health. Conclusive evidence on this question has not yet been obtained, although it has been the sub-

ject of controversy for several years. During the summer of 1909 a large number of observations were made on the body temperature of weavers in humid sheds, as a result of which Dr.

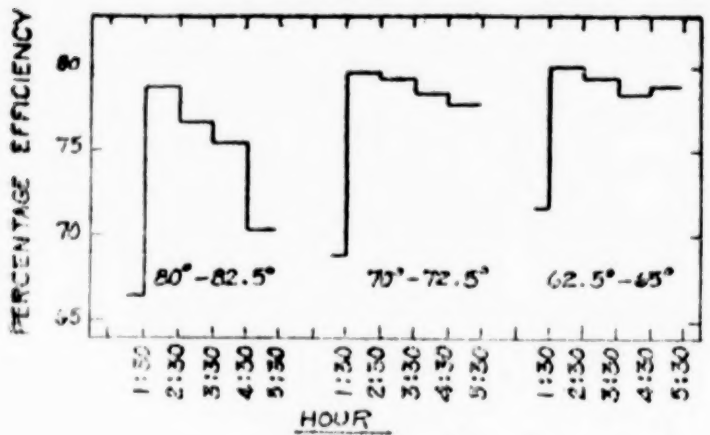

FIG. 4.—Relation between hourly variation in efficiency and temperature.

Legge states that "A rise of mouth temperature makes itself distinctly felt when the temperature of the wet-bulb exceeds 75°F., in other words, weavers are likely to be, when this is the case, working under adverse physiological conditions" (15). This conclusion was corroborated by Dr. Pembrey and Dr. Collis (3), who state that "Our observations show that the influence of the warm moist atmosphere is to diminish the difference between the internal temperature of the body and that of the peripheral parts. This is exactly the condition which would explain the discomfort and low state of health of which many of the weavers complain." They further state that "The prolonged exposure to the hot moist atmosphere would appear to be more injurious than exposure to even higher temperatures (wet-bulb) for a shorter time, and, we consider, it would be an advantage to fix the limit of the wet-bulb temperature as low as possible, after every allowance has been made for the difficulties of weaving, and the breaking of threads."

It accordingly appears to have been established beyond doubt that exposure to warm, moist atmospheres produces a rise in body temperature. Although this fact is physiologically important, it suggests, but does not prove, that such atmospheric conditions may be detrimental to health. A final answer to the latter question will only be obtained when the sickness and mortality records of weavers employed in dry and humid sheds are available for purposes of comparison.

During 1924 a report was published by the medical officer of health for Blackburn (Dr. W. Allen Daley) which contains some figures on the death rate of cotton operatives in that town (18). These are reproduced in Table 7. The figures show that the death rate is lowest among weavers and highest among spinners. They corroborate the figures given by Dr. Greenwood for the same town in the period 1889 to 1912, *viz.*:

Weavers	6.3
Spinners	15.0
Winders, etc.	7.7
Cardroom	10.1
Whole borough	14.2

Dr. Daley therefore suggests that the low death rate among weavers is not accidental, and concludes that, "so far as the death rates show, weaving in humid sheds such as there are in Blackburn is healthier than the other branches of cotton manufacture as carried out in this town."

Before accepting the foregoing results as conclusive, it must be remembered that:

1. The numbers given as actually employed are based on the census returns for 1921, which may not cor-

respond to the numbers exposed to the shed conditions during the period 1920 to 1922.

2. The death rate among female operatives is undoubtedly underesti-

3. The average age of all weavers may be less than that of the operatives in the other groups. If so, one would expect to find a lower death rate among weavers.

TABLE 7.—DEATH RATE PER THOUSAND EMPLOYED FROM ALL CAUSES, 1920 TO 1922[1]

SEX	WEAVERS		SPINNERS		WINDERS, ETC.		CARDROOM		DEATH RATE FOR WHOLE BOROUGH
	Number Employed	Death Rate	Number Employed	Death Rate	Number Employed	Death Rate	Number Employed	Death Rate	
Both sexes	24,077	4.2	1,950	9.6	4,901	8.3	1,481	7.0	14.1
Female	17,788	3.3	1,101	5.7	4,187	6.7	1,048	4.8	13.1
Male	6,289	6.9	849	(14.8)	714	(17.7)	433	(12.3)	15.4

[1] Figures in parentheses are based on populations less than 1,000 and are therefore not reliable.

mated. In weaving, for instance, it is less than half that for the males. This, as Dr. Daley points out, is largely due to the fact that weavers who are away from work for some time before death may be classed as housewives. Although Dr. Daley states that this classification would affect all classes of female operatives to a proportional extent, the assumption involved is rather questionable. It is conceivable, for instance, that if a humid atmosphere is detrimental to health, the weavers affected might give up work or at least find a less harmful occupation. If this were so, the returns given above would relate to a selected group of weavers, and would underestimate the actual effect of humid conditions on mortality.

The foregoing considerations may or may not have a significant influence on the mortality figures given in the table, but until their possible effects have been ascertained, the latter cannot be accepted as final and conclusive.

A general and detached consideration of the position of weavers in humid sheds compels us to recognize that such operatives are exposed for a period of forty-eight hours a week, or about one-half of the waking life, to artificially created atmospheric conditions which are appreciably hotter, more humid, and more stagnant than those of the outside air.

Constitutionally the weaver is equipped to live most comfortably and effectively in an atmosphere which approximates the average conditions

of the outside air, and any appreciable deviation from such conditions will modify the normal functioning of the physiologic mechanism. At the same time, it must be remembered that the unfavorable effects of exposure to unusual or abnormal atmospheric conditions are mitigated to a certain extent by the ability of the human organism to adapt itself to such conditions. Interesting evidence in this connection is presented by Vernon (13, p. 143), who, as the result of experiments, found that the endurable limits of air temperature are greatly affected by acclimatization. Toward the end of an experimental series it was about 6°F. higher than in the experiments made a month earlier. The same writer also states that, at the outset, experiments in moist air were much more trying than those in relatively dry air, but after acclimatization the reverse was the case. Similar examples of adaptation to high temperatures are provided by Sutton (19) who found that for the same rise of body temperature, when exposed to a hot, moist atmosphere, the increase in oxygen consumption decreased from 98 per cent. to 70 per cent. and afterwards to 55 per cent., as the experiment was repeated at different times separated by a few days. Experimental evidence of this nature indicates that a similar process of adaptation would be found in the case of industrial operatives exposed to high temperatures and humidities, and that the investigator of industrial conditions must take this factor into consideration when considering the effect of such conditions on the comfort, health, and efficiency of the operatives. The occasional visitor to the factory, and even the employers' or operatives' representatives, frequently talk and act as if the power of adaptation were nonexistent, with the result that hot and humid atmospheres in industry are condemned without qualification or reserve.

That a certain amount of adaptation takes place is an established fact; within limits, industrial operatives are able to endure atmospheric conditions which would cause discomfort and distress to individuals habituated to the conditions provided by the outside air. Vernon and Bedford (20) had the importance of adaptation forced on them when making observations on the atmospheric conditions in potters' shops. Similar signs are noticeable in laundries and humid weaving sheds. Unless adaptation occurred, work under some industrial conditions would be carried out with great difficulty and reduced efficiency, and in some cases would be practically impossible. The ultimate effect of continued exposure to unusual atmospheric conditions, such as those mentioned in connection with the cotton industry, has not yet been established. Whatever it may be, it appears evident that its extent will be reduced because of the power of adaptability of the human organism.

Possible Improvements

Any attempt to improve the atmospheric conditions in humid sheds must take into consideration the possibility of (*a*) reducing the temperature, (*b*) reducing the amount of water vapor in the air, and (*c*) increasing the rate of air movement in the vicinity of the operatives. The situation is complicated because of the opposite effects of

a warm, moist atmosphere on (*a*) the operatives and (*b*) the yarn used in the weaving process. Ideally, the difficulty could be overcome by creating a different atmosphere for the warp and the weaver by introducing some system of local humidification. Such a system is described by Hill (1, p. 111) and the Commission on Ventilation and Humidity in Weaving Sheds (15, p. 14), but the apparatus was found to be unsatisfactory. Satisfactory conditions could be obtained by the discovery of a method of treating and preparing the warp which would make its economic manufacture independent of temperature and moisture, and such a line of research would be a profitable undertaking for the Cotton Research Association. Until some such discovery is made, it will be necessary to concentrate on the temperature, humidity, and amount of air movement in weaving sheds.

As to temperature, a very thorough and extensive investigation has shown (15, p. 35) that the possibilities of controlling this factor are very limited. In this inquiry the rise in temperature in a humid shed was found to be dependent on the combined effects of:

1. The power absorbed by the machinery.
2. The bodily heat of the operatives.
3. The steam used for conditioning the atmosphere.
4. The radiant heat of the sun.
5. External sources of heat such as adjacent flues and boiler houses.

In cloudy weather, about two-thirds of the rise in temperature may be attributed to mechanical work, the remainder being due in almost equal proportion to the bodily heat of the operatives and the steam introduced for humidifying purposes. The effect of solar radiation is also very considerable, and may add as much as 40 or 50 per cent. to the total rise in temperature. It is obviously practically impossible to reduce the temperature by restricting the amount of heat passing into the shed atmosphere from the first two sources mentioned above, but the heat introduced by the conditioning apparatus and that due to external sources can frequently be materially reduced. The investigation in question accordingly concentrated on these aspects of the situation, and the results obtained may be summarized as follows:

1. The effect of solar radiation may be reduced by whitewashing the roof during the summer months.
2. By means of roof sprays, the average shed temperature on sunny days may be reduced by 2°F. or 3°F.
3. A more efficient ventilation of the sheds during the night will secure a greater cooling effect.
4. When only a low percentage of humidity is required, wet matting and sprays placed at the inlet of the ventilation ducts will be efficient and considerably improve the conditions prevailing in the shed.
5. Humidification by atomized water instead of steam jets reduced the temperature by 6.7°F. in one shed and 4.5°F. in another.
6. Any roof having satisfactory insulating properties, such as double or concrete roofs, diminishes the range of temperature within the shed, and hence excessive temperatures are reached less frequently.

Thus a significant decrease in the shed temperature may be obtained by adopting one or more of the foregoing methods, but the extent of the possible reduction is limited, and the resulting temperature will still be high. In this connection some firms of ventilating engineers claim that, by means

of their systems, a dry bulb temperature of 72.5°F. and a relative humidity of 80 per cent. can be maintained throughout the summer months. So far as is known, such a system does not appear to have been installed in a humid weaving shed, presumably because of the prohibitive cost.

The amount of water vapor in the shed atmosphere can be controlled to a much greater extent than the temperature, because the introduction of steam for humidifying purposes is under the control of the management. Since, however, a considerable amount of moisture is necessary for manufacturing purposes, the relative humidity of the air in the shed must be maintained at a fairly high level.

Since the effect on the operatives does not depend on the relative humidity but on the absolute amount of vapor present in the air, it should be possible to create a condition which will be fairly satisfactory both to the warp and to the weaver. Thus, with a temperature of 70°F. and a relative humidity of 83 per cent., the amount of water vapor in a cubic foot of air is only 6.7 grains; with a temperature of 75°F. and a relative humidity of 84 per cent., it is only 5.9 grains. Such conditions of temperature and humidity will insure a high degree of efficiency from the manufacturing standpoint, yet will enable work to be done in comparative comfort because the evaporative power of the air (as to superficial moisture on the body) is still great. The rate of evaporation of moisture from the yarn depends on the relative humidity, since the yarn is at approximately the same temperature as the air in the shed. A relative humidity of 83 or 84 per cent. will, therefore, keep the yarn sufficiently moist for manufacturing purposes. The rate of evaporation of moisture from the body depends, on the other hand, on the difference between the actual amount of water vapor in the air and the amount it would contain if saturated at body temperature. When in the latter condition it is capable of containing 18.7 grains per cubic foot, consequently, with the temperatures and humidities given above, the rate of evaporation of moisture from the body and the accompanying cooling effect will still be great. Thus, provided the temperature is not too high (70°F. to 75°F.), it is possible to obtain conditions which are comparatively satisfactory both from the standpoint of the yarn and from the standpoint of the operatives. Ventilating and humidifying systems which are capable of maintaining such conditions should consequently be carefully considered.

Perhaps the most promising methods of improving the atmospheric conditions in humid sheds are those which attempt to increase the rate of air movement in the vicinity of the operatives. By this means unfavorable effects of high temperatures or humidities can be neutralized and conditions obtained which enable work to be performed with comparative comfort and efficiency. An increase in the rate of air movement has the same cooling effect on the body as a reduction in temperature or the amount of water vapor in the air, and since modification along these lines is considered undesirable from the manufacturing standpoint, the possibilities associated with air movement become increasingly important.

The rate of air movement in weaving sheds can be increased by utilizing different devices or methods. During the summer, a number of wooden paddles were fixed to the line shafts in

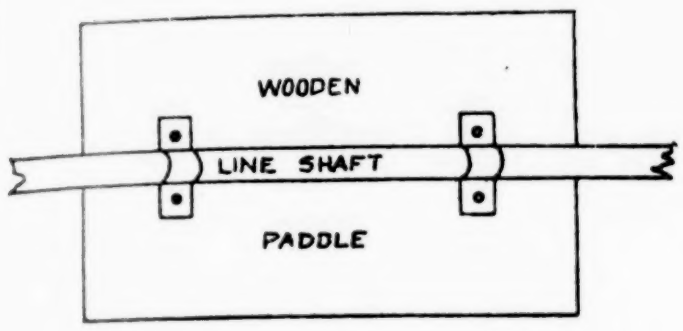

FIG. 5.—Wooden paddle used in air movement experiments.

a Blackburn weaving shed, in the manner indicated in Figure 5. The paddles were about 2 feet in length and 1½ feet in width and the line shaft revolved at the rate of 110 revolutions per minute. Air movement tests were made at head level position (1) directly under a paddle and (2) in an adjoining alley without paddles. The results showed that the rate of air movement directly under the paddles was 31 feet per minute, and at the same level away from the paddle 28 feet per minute. Thus the paddle fails to produce an appreciable increase in the rate of air movement in the vicinity of the operatives and is accordingly quite useless for practical purposes. The paddle revolves much too slowly to have an appreciable effect on the movement of the air in the vicinity of the operatives; a further objection would be the trouble involved in removing all the paddles from the shafts at the end of the warm summer months.

Ideally, the best effects will be obtained when the air currents in the vicinity of the operatives are somewhat variable, and are capable of being modified in intensity as the occasion demands. Such conditions can be obtained by the use of suitable electric fans, and the results of a few experiments along these lines may be mentioned. These experiments were carried out in the ironing and calendering departments of a handkerchief works, and the final disposition of the fans in relation to the workers concerned is shown in Figure 6. Fan A (Fig. 7) is the ordinary type of oscillating fan giving 1,400 revolutions per minute. It was placed on a platform 8 feet, 8 inches above floor level and the plane of the blades was directed

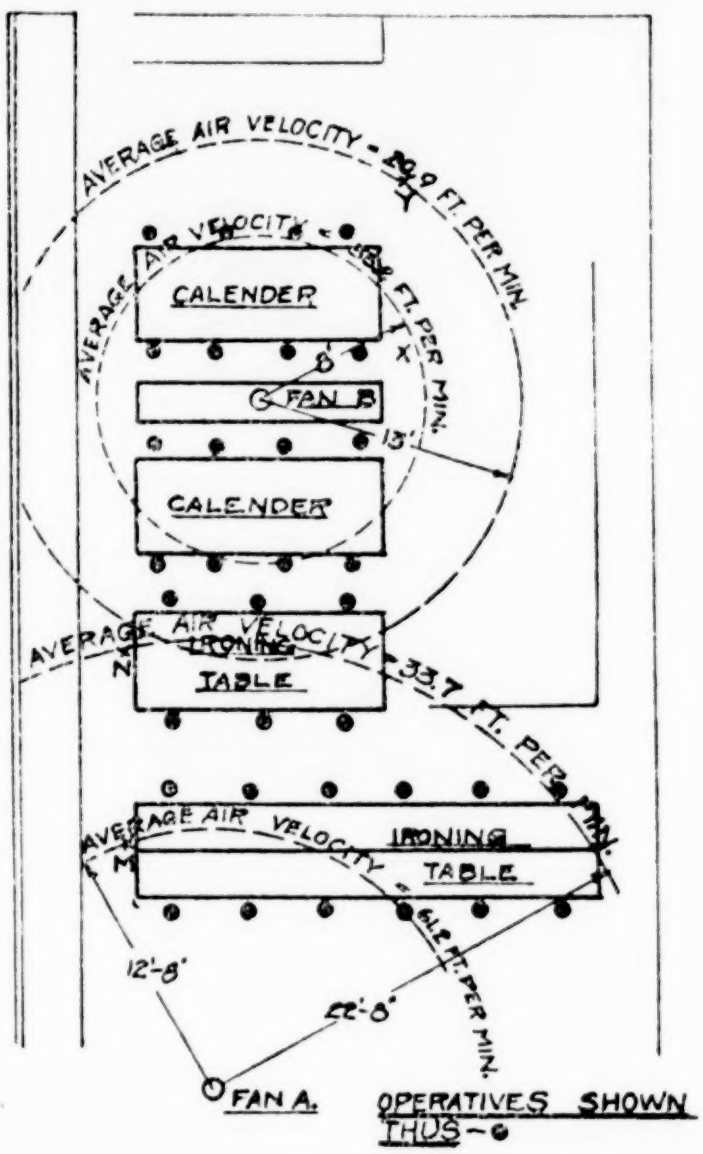

FIG. 6.—Position of fans and operatives in ironing and calendering departments of a handkerchief works.

slightly downward. The fan oscillated backward and forward through an angle of 90°, at the rate of one complete oscillation in twenty seconds. Readings were taken in head level

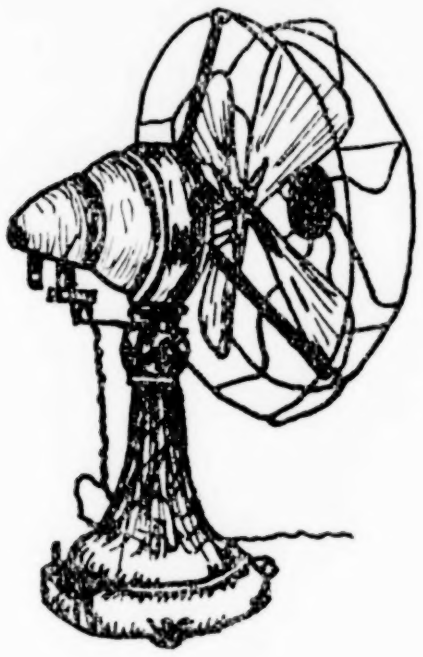

FIG. 7.—Type of fan used in position A (Fig. 6).

position at distances of 12 feet, 8 inches (position M) and 22 feet, 8 inches (position N) from the fan; first when the fan was moving and afterward when it was stopped. The results obtained are given in Table 8. In the first position (M) the fan caused an increase in the rate of air movement of 231 per cent. and an increase of 111 per cent. in position N. The area affected by the fan is shown by the dotted lines (Fig. 6); thus the beneficial effects were felt by all the ironers. At the moment when the fan was directed to any one of the ironers, the operative in question experienced the full force of the air current, which, of course, was much greater than the values given above, representing the average rate of movement during a period of approximately one and one-half minutes. Thus in any given position, operatives were fanned by periodic breezes which attained a maximum velocity of approximately 150 feet per minute. These variable air currents were much appreciated and added considerably to the comfort of the operatives when working.

TABLE 8.—EFFECT OF FAN ON AIR MOVEMENT (IRONING PROCESS)

POSITION	DRY BULB	WET BULB	AIR VELOCITY	CONDITIONS
	°F.	°F.	ft. per min.	
M	73.0	65.5	61.2	Fan running.
M	72.9	66.0	18.5	Fan stopped.
N	70.9	63.9	33.7	Fan running.
N	70.7	64.6	16.0	Fan stopped.

Fan B (Fig. 8) was of the rotary type and was suspended from the ceiling so that the center of the blades was 8 feet, 8 inches above floor level. The length of each blade was 12 inches and the blades revolved at a rate of 1,400 revolutions per minute. The fan had a complete rotary movement and the center of the blades rotated in a horizontal plane once in twenty-seven seconds. The plane of the blades was directed downward and made an angle of 40° with the vertical. The effect of the fan was accordingly felt over a wide area; and as it was placed in a central position above the calender machines, it proved to be a very economical and effective means of increasing the air movement in the vicinity of the calender operatives. Observations were made in two positions (X and Y) which were 6 feet and 5 feet above floor level, and 8 feet and 13 feet from the fan, respectively.

From the results obtained, which are given in Table 9, it will be seen that the fan is responsible for an average increase in air movement in position X amounting to 107 per cent., and 87 per cent. in position Y. As in the former case, the full force of the air current in any given position is felt only for a few seconds once every half minute; the varying nature of the air currents produced by the fan in the vicinity of the operatives is pleasing and stimulating. If a uniform current of air were continually directed toward each operative, the body would tend to become adapted to such conditions and the stimulating effect of a variable air movement would accordingly be less perceptible. In the present case, the conditions could have been still further improved by speeding up the horizontal rotary movement of the fan; this modification is now being introduced. Both the management and the operatives were unanimous in their appreciation of the beneficial effects produced by the two fans. The running cost is almost negligible, and they can be switched on and off according to the nature of the atmospheric conditions in the room.

TABLE 9.—EFFECT OF FAN ON AIR MOVEMENT (CALENDERING PROCESS)

POSITION	DRY BULB	WET BULB	AIR VELOCITY	CONDITIONS
	°F.	°F.	ft. per min.	
X	71.7	63.1	35.2	Fan running.
X	70.8	62.6	17.0	Fan stopped.
Y	71.9	62.3	20.9	Fan running.
Y	72.2	62.3	11.2	Fan stopped.

The value of a fan as a means of increasing the rate of air movement is also illustrated by some observations made in a laundry. In this case the fan was fixed to a beam in the calender department and the blades revolved in a horizontal plane about 15 feet above floor level. The fan was much larger than the type in general use (see Fig. 9) and was capable of producing a powerful current of air over a wide area. The over-all diameter of the fan was 7 feet, the number of blades on the fan 18, and each blade was 3 feet in length. Observations were made in a position about 5 feet above floor level at a distance of 6 feet from a point directly under the center of the fan, and the results obtained are given in Table 10. The slower rate is adopted during the cooler winter

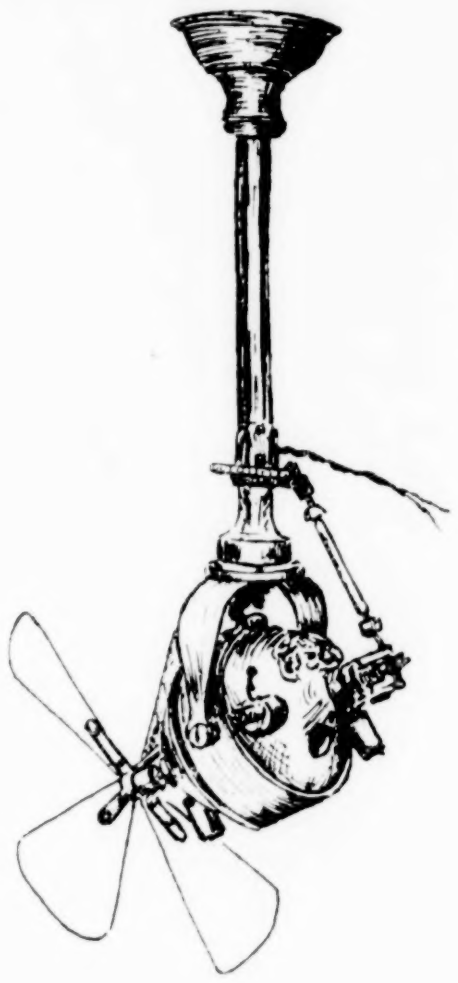

FIG. 8.—Type of fan used in position B (Fig. 6).

months and the higher rate in the hotter summer period. Thus the fan produced a considerable increase in the rate of air movement in the vicinity of the calender operatives, and

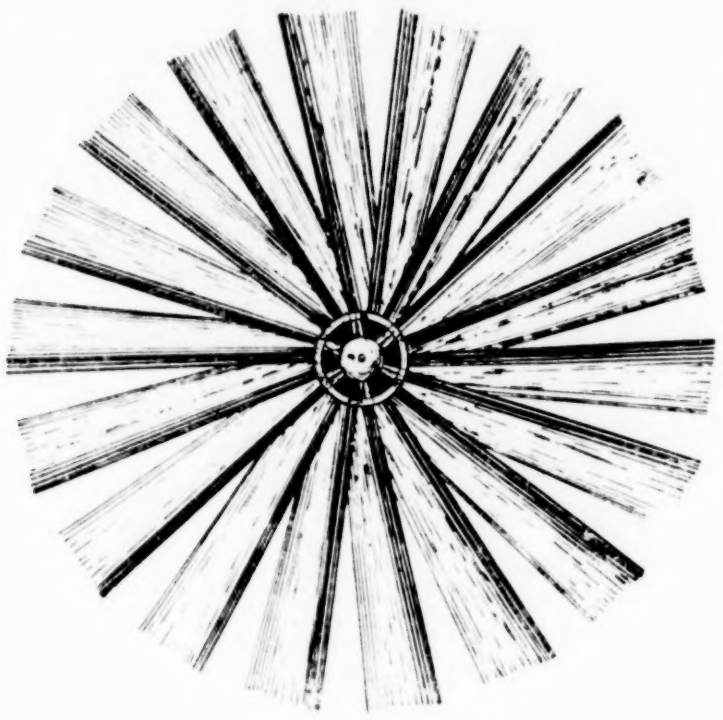

FIG. 9.—Type of fan used in laundry experiments.

enabled them to work with greater comfort and efficiency. Prior to the installation of the fans, cases of fainting were fairly frequent, as the operatives were usually exposed to a dry bulb temperature varying from 90°F. to 100°F., and a wet bulb which ranged from 70°F. to 80°F. The introduction of the fans, however, has improved the conditions to such an extent that fainting cases are now unknown. The effect of unsuitable atmospheric conditions can, then, be mitigated to a considerable extent by increasing the rate of air movement in the neighborhood of the operatives. The laundry results show that, by means of suitable fans, an air velocity of 200 per minute can be obtained, and what is possible in a laundry is also possible in a weaving shed. The increased air movement was welcomed by the operatives and they were unanimous in their approval of its beneficial effects. The laundry fans were driven from the line shafts by means of belts and pulleys, and the cost of running was accordingly very small. In a crumpet bakery the like benefit was obtained for the operatives by blowing the warm air about without harm to the crumpets (Farmer).

TABLE 10.—EFFECT OF FAN ON AIR MOVEMENT (LAUNDRY)

CONDITIONS	AIR VELOCITY
	ft. per min.
Fan stopped	32
Fan running at 53 revolutions per minute	89
Fan running at 74 revolutions per minute	208

An increase in the rate of air movement is associated in the minds of many people with the production of drafts, and in some instances, the introduction of devices for increasing air movement has been opposed because of the supposed existence of this objectionable feature. Female operatives who are no longer young appear to be particularly sensitive to air movement and its imagined consequences, and take every precaution to protect themselves from its influence. A draft, as such, is most noticeable when a cool current of air impinges on a small area of the skin, as, for instance, when the cooler outside air passes through a broken pane in the window and strikes the neck of a person inside who is adapted to the warmer air of the room. In the foregoing experi-

ments, the warmer air of the room is merely recirculated by the fans, and the feelings usually associated with a draft are wholly absent. That greatly increased movement of air under such conditions has no harmful effects is shown by the laundry observations, in which the operatives are constantly exposed, with beneficial results, to a breeze of approximately 200 feet per minute (*cf.* the usual rate of air movement in weaving sheds which is 24 feet per minute).

It will probably be suggested that since an increase in the rate of air movement promotes the evaporation of moisture from the body, it will have a similar, and consequently an undesirable effect, on the moisture in the yarn. But the rate of evaporation of moisture from the yarn is almost entirely dependent on the relative humidity of the surrounding air, which remains unchanged when the rate of air movement is increased; whereas the rate of evaporation of moisture from the body is dependent on the absolute humidity of the air and is affected by air movement in the manner previously described.

The efficacy of air movement as a means of increasing the bodily comfort and efficiency of weavers is partially dependent on the nature and quality of clothing worn by these operatives. Open-meshed fabrics which fit loosely around the body facilitate the movement of air between the clothing and the skin surface, and thereby prevent the air in contact with the body from becoming hot and moist. Bare arms and clothing open at the neck are advantageous in promoting loss of heat from the body. The less the amount of clothing worn, and the more freely it hangs about the body of the operative, the greater will be the resulting comfort and efficiency. Conventional modesty is frequently at variance with physiologic necessities, and comfort is sacrificed for the sake of appearance. Education in the matter of suitable clothing and in the need for compensating for the warm, moist factory life by some measure of open-air exercise and open windows in sleeping rooms will do a great deal to keep up the health of the operatives.

The practice adopted by some operatives of hanging their outer garments on the walls of the shed is to be condemned. Such garments become almost saturated with moisture at the temperature of the shed, and the change to the cooler outside air causes some of the moisture to condense and the garments to feel damp. The outer clothing should be left in a fairly warm and dry apartment adjoining the shed.

Existing regulations in connection with humid weaving sheds are concerned with the chemical purity, the temperature, and the humidity of the shed atmosphere. They should be based on the cooling power of the air in relation to the human body, and a standard of cooling should be adopted which would insure the maintenance of an adequate flow of heat from the body under different atmospheric conditions. Existing regulations ignore the value of air movement, but this factor would receive due consideration if the cooling power of the air were adopted as the criterion of suitability and comfort. It would be a relatively simple matter to compile a table giving the rate of air movement necessary to maintain a satisfactory

cooling rate for different wet and dry bulb temperatures, and to regulate the rate of air movement in accordance with these temperatures. By this means a temperature and relative humidity could be maintained suitable for manufacturing purposes, while preserving at the same time the bodily comfort and efficiency of the operatives.

Future Possibilities

An attempt has been made to indicate the general effect of high atmospheric temperatures and humidities on the bodily comfort and working capacity of operatives exposed to such conditions. In particular, existing conditions in humid weaving have been described and the possibilities of improvement discussed. Unfortunately reliable evidence on the effects of prolonged exposure to the atmospheric conditions in humid sheds is meager and incomplete, and it may be useful to indicate the possible lines of future research on this question.

In the first place, it is desirable to obtain more accurate and comprehensive information on the relation between temperature, humidity, and the number of yarn breakages for different kinds of yarn. Although yarn in humid sheds weaves more easily (because of fewer breakages) as the temperature or relative humidity increases, it is not known if the decrease in the number of breakages is directly proportional to the increase in temperature or humidity. Possibly, beyond a certain point, any further increase in temperature or humidity may fail to have an appreciable effect on the number of breakages; if so, such limits should be determined. Further, the different qualities of yarn used in the manufacturing process, and the various methods of preparation adopted, render each kind of warp susceptible to breakages to very different degrees. There is also some evidence to show that inequalities in the yarn, due to these causes, may have a greater effect than the atmospheric conditions on the frequency of breakages. The determination of the relation between temperature, humidity, and yarn breakages could be satisfactorily carried out by observing the nature and number of loom stoppages over a period of several days, and noting at the same time hourly readings of the wet and dry bulb thermometer.

Closely related to this problem is the question of determining the relation between the atmospheric conditions of the shed and the working capacity of the operatives. Some evidence in this connection has already been obtained, but a more extensive investigation, preferably in a small experimental shed, in which the atmospheric conditions could be regulated and controlled, would yield more definite and conclusive results.

In the preceding remarks it has been stated that the properties of the air which determine the rate of heat loss from the body are: (*a*) its temperature, (*b*) the amount of water vapor it contains, and (*c*) its rate of movement. As to the first two factors, from the standpoint of cooling power and comfort, the unfavorable effects of an increasing temperature may be neutralized by a suitable reduction in the amount of water vapor contained in the air. This possibility has been thoroughly and systemati-

cally examined by American engineers (21), and different combinations of wet and dry bulb temperatures which are experienced as equally comfortable have been experimentally determined. The figures given in Table 11 illustrate the kind of results obtained. Each combination of wet and dry bulb temperature produced the same feelings of comfort in individuals exposed to the different conditions. Thus the effect of a rising dry bulb temperature is neutralized by the effect of a falling wet bulb, and conditions of equal comfort are produced in each case. If the results in Table 11 are represented graphically, a curve AB is obtained (see Fig. 10) which is termed an equal comfort line, since any point on this curve corresponds to a combination of wet and dry bulb temperatures which enable individuals exposed to such conditions to experience an equal degree of comfort in each case. Thus point C on the curve (corresponding to a wet bulb temperature of 58.5°F. and dry bulb of 69°F.) will produce the same experience of comfort as point D (corresponding to wet and dry bulb temperatures of 56°F. and 71°F., respectively).

TABLE 11.—COMBINATIONS OF WET AND DRY BULB TEMPERATURES GIVING CONDITIONS OF EQUAL COMFORT

DRY BULB	WET BULB
°F.	°F.
64.0	64.0
65.0	63.0
66.0	62.0
67.1	60.7
68.2	59.4
69.4	58.0
70.7	56.4
72.3	54.5
73.8	52.4

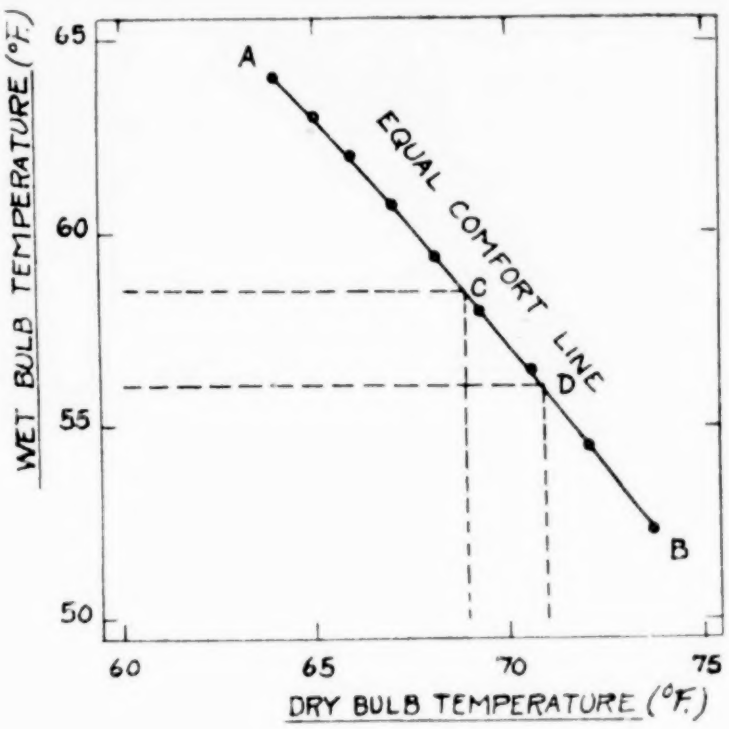

FIG. 10.—Equal comfort line corresponding to values given in Table 11.

Equal comfort lines for other combinations of the wet and dry bulb have also been obtained and these are represented in Figure 11. Thus, points along a line such as AB represent conditions which are equally comfortable. For instance, point C, corresponding to a dry bulb temperature of 75°F. and a wet bulb of 66°F., will be just as comfortable as conditions represented by point D, which corresponds to a dry bulb of 85°F. and a wet bulb of 56.5°F. All points lying along this line are said to have the same *effective* temperature (in this case, 70°F.). Similarly all the lines which are approximately parallel to AB represent effective temperatures differing from each other by one degree. The results of a large number of experimentally determined observations have shown that the most comfortable conditions are obtained when the effective temperature is 64.5° (line XY) and that the true zone of comfort lies between

effective temperatures of 62°F. and 69°F. (shaded portion). Conditions corresponding to any point within this zone will be experienced as comfortable, but the most comfortable temperatures will correspond to conditions lying along line XY. The foregoing results are true for still-air conditions and inactive individuals wearing ordinary clothes.

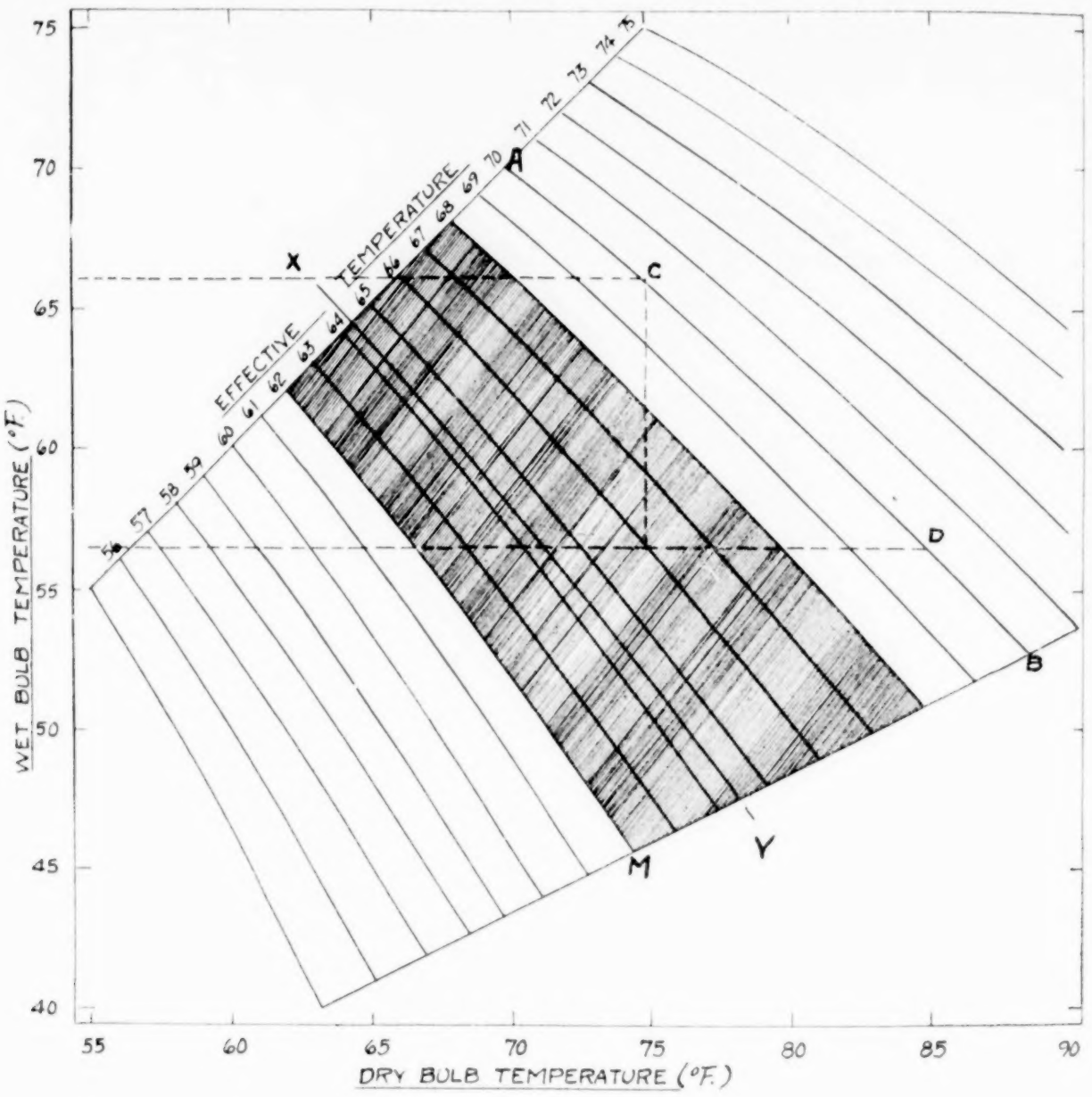

FIG. 11.—Equal comfort lines corresponding to various combinations of wet and dry bulb temperatures.

With moving air, the same degree of comfort is experienced with higher wet and dry bulb temperatures, as the figures in Table 12 show. They represent the different wet and dry bulb temperature combinations which give conditions of equal comfort in (*a*) still air; and with air velocities of (*b*) 50, (*c*) 100, and (*d*) 200 feet per minute. Thus it is seen that by increasing the rate of air movement the effect of high wet and dry bulb temperatures can be neutralized, and, as the table shows, saturated air at 72.8°F. moving with a velocity of 200 feet per minute is just as comfortable to bear as saturated air at 64°F. which is still.

Charts similar to Figure 11, but showing the effect of different air velocities on comfort, have been constructed by the American investigators, and are fully described in the reports mentioned. Up to the present time the results obtained relate only

to individuals at rest, but the determination of the most comfortable conditions for various forms of activity is now in progress. The value of this work lies in the actual determination of different atmospheric conditions which are experienced as equally comfortable by a representative number of individuals exposed to them. The results obtained show the interdependence of wet bulb temperature, dry bulb temperature, and air movement, and the importance of their compensatory effects in relation to bodily comfort. When the most suitable effective temperatures for different forms of industrial activity have been established, it will be possible, by means of suitable charts, to ascertain at a glance the various combinations of wet bulb temperature, dry bulb temperature, and air movement, which will give the conditions desired. The possibility of being able to determine such facts is of great importance, but the ultimate benefit to industry will depend on the ability to reproduce and maintain such conditions. Ventilating systems which fulfil these requirements now exist, and industrial employers will undoubtedly give them the consideration and attention they deserve. Suppose, for instance, it is established beyond dispute that weavers in the cotton industry can work with maximum comfort at an effective temperature of 64°F. By means of the charts it will be possible to find the particular combination of wet bulb, dry bulb, and rate of air movement which approximates most closely the desired optimum, and at the same time enables the yarn to be manufactured with a minimum number of breakages. Research along the lines indicated is undoubtedly of the utmost importance, and must be taken into consideration whenever an attempt is made to improve the atmospheric conditions in the weaving industry.

TABLE 12.—CONDITIONS OF EQUAL COMFORT IN STILL AND MOVING AIR

STILL AIR		AIR MOVING AT RATE OF (*ft. per min.*)					
		50		100		200	
Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
64.0	64.0	67.3	67.3	69.9	69.9	72.8	72.8
65.0	63.0	68.2	66.1	70.7	68.5	73.6	71.3
66.0	62.0	69.1	65.0	71.4	67.0	74.3	69.8
67.1	60.7	70.1	63.4	72.3	65.4	75.1	68.0
68.2	59.4	71.1	61.9	73.3	63.8	76.0	66.1
69.4	58.0	72.3	60.3	74.3	62.0	77.0	64.2
70.7	56.4	73.4	58.5	75.4	60.0	77.9	62.0
72.2	54.5	74.7	56.4	76.5	57.6	78.8	59.2
73.8	52.4	76.5	53.9	77.8	55.0	79.7	56.2

More important still is the determination of the effect of high atmospheric temperatures and humidities on the health and mortality of the operatives. The relation to sickness should be ascertained by compiling a careful record of the amount of time lost due to sickness in the case of weavers employed in dry and humid sheds, preferably in the same town and living under similar environmental conditions. The only significant variable in the statistics used for comparative purposes should be different atmospheric conditions existing in dry and humid sheds. The mortality return should be compiled with equal care and be free from the objections

already mentioned.[1] The collection of such records would settle finally and conclusively the long-standing controversy as to whether prolonged exposure to the atmospheric conditions in humid sheds is detrimental to health.

Finally, the discovery of some method of treating the yarn which will enable the manufacturing process to be carried out under ordinary atmospheric conditions is within the limits of possibility. Such a discovery would be of vital importance to the weaving section of the cotton industry and would revolutionize the conditions of manufacture. Attention should accordingly be concentrated on this question without delay.

Summary

General Considerations.—The loss of heat from the body, and the consequent preservation of a suitable body temperature, is dependent on (*a*) the temperature of the surrounding air, (*b*) its rate of movement, and (*c*) the amount of water vapor it contains; further, (*d*) the rate of heat loss will also be affected by the kind and amount of clothing worn. Finally, in cases of increased activity, the greater amount of heat produced in the body necessitates a greater rate of heat loss by one or more of the processes mentioned.

Effect of Unsuitable Atmospheric Conditions.—(*a*) Prolonged exposure to warm, moist, and stagnant atmospheres imposes a strain on the heat-regulating mechanism of the body, and tends to have an unfavorable effect on vitality and efficiency. The body becomes overheated, the activity of the heart is increased, metabolism is reduced, and the inclination and ability to do work are lowered.

(*b*) Considering separately each of the factors involved in the maintenance of a suitable body temperature, it has been shown that:

1. High atmospheric temperatures in industry have an adverse effect on bodily comfort and productive efficiency.

2. The endurable limits of temperature can be raised and output increased by increasing the rate of air movement in the vicinity of the body.

3. When the amount of water vapor in the air exceeds a certain limit (about 75°F. wet bulb), the body temperature rises, efficieney decreases, and the operatives are working under adverse physiologic conditions.

Existing Conditions in Humid Weaving Sheds.—(*a*) In many sheds, the average temperature throughout the year is from 70°F. to 75°F. and during the hot summer months temperatures of 85°F. to 90°F. are often attained.

(*b*) The average rate of air movement is approximately 24 feet per minute. This rate is quite imperceptible, and compares unfavorably with the conditions in many other industries and with pleasant conditions outside.

(*c*) Observations carried out in certain sheds showed that in summer the wet bulb temperature exceeds 70°F. for three-fourths of the working time, and 75°F. for one-fourth of the total hours worked.

Effect on Efficiency and Health.—(*a*) In humid weaving sheds, the number of yarn breakages decreases, and consequently output tends to increase

[1] See pp. 328–329.

as the temperature and humidity increase.

(*b*) Beyond a certain point (about 70°F. to 75°F. and a relative humidity of 80 to 85 per cent.), efficiency begins to decrease because of the adverse effects of the atmospheric conditions on the weaver.

(*c*) The hot, moist atmosphere in humid sheds causes a rise in body temperature when the wet bulb temperature exceeds 75°F., and when this occurs the weavers are working under adverse physiologic conditions.

(*d*) Definite information on the sickness and mortality rates of operatives employed in humid sheds has not yet been obtained.

(*e*) The effect of hot, moist atmospheres on the human organism is mitigated to some extent by the ability of the physiologic mechanism to adapt itself to unusual conditions. This is a fact of considerable importance, and must be taken into consideration when attempting to determine the most suitable atmospheric conditions for operatives in humid sheds.

Possible Improvements.—(*a*) The temperature in humid sheds may be reduced to a slight but significant extent by adopting one or more of the following devices:

1. Whitewashing the roofs during the summer months.
2. Roof sprays.
3. Wet matting and sprays placed at the inlets of the ventilation ducts.
4. Humidification by atomized water.
5. Insulating the roof.

(*b*) Since the comfort of the operatives depends on the absolute humidity of the air, while the frequency of yarn breakages depends on the relative humidity, conditions which are fairly suitable both for the weaver and for the warp may be obtained with a humidity of 80 to 85 per cent., provided the temperature of the shed does not exceed 70°F. to 75°F. Ventilating systems which are capable of maintaining such conditions should accordingly be carefully considered.

(*c*) The effect of high temperatures and humidities may be mitigated to a considerable extent by increasing the rate of air movement in the vicinity of the operatives. This may be effected by the use of suitable fans, driven either electrically or from the line shafts.

(*d*) The adoption of a more suitable type of clothing by the operatives will promote the dissipation of heat from the body and enable the work to be done with greater comfort.

Future Investigations Needed.—(*a*) An extensive inquiry into the relation between different atmospheric conditions and the working capacity of the operatives.

(*b*) An investigation of the effect of high atmospheric temperatures and humidities on the health and mortality of operatives.

(*c*) The discovery of some method of treating the yarn which will enable the manufacturing process to be carried out under more satisfactory atmospheric conditions.

BIBLIOGRAPHY

1. Hill, L.: The Science of Ventilation and Open Air Treatment. Part I. Med. Res. Council, Special Rep. Series No. 32, p. 18. London, H. M. Stationery Office, 1919.
2. Hill, L.: The Science of Ventilation and Open Air Treatment. Part II. Med. Res. Council, Special Rep. Series No. 52, p. 226. London, H. M. Stationery Office, 1920.
3. Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds. Second Report, 1911 (Cd. 5566). Appendix III, p. 24.
4. Vernon, H. M.: The Influence of Hours of Work and of Ventilation on Output in Tinplate Manufacture. Indust. Fatigue Res. Board, Rep. No. 1. London, H. M. Stationery Office, 1919.
5. Vernon, H. M.: Unpublished Observation.
6. Report of the New York State Commission on Ventilation. New York, E. P. Dutton & Co., 1923, p. 197.
7. Third Annual Report of the Industrial Fatigue Research Board to 31st December, 1922. London, H. M. Stationery Office, 1923.
8. Houghten, F. C., and Yagloglou, C. P.: Cooling Effect on Human Beings Produced by Various Air Velocities. Jour. Am. Soc. Heating and Ventil. Eng., 1924, *30*, 182.
9. Haldane, J. S.: The Influence of High Air Temperatures. Jour. Hyg., 1905, *5*, 494.
10. Orenstein, A. J., and Ireland, H. J.: Experimental Observations upon the Relation between Atmospheric Conditions and the Production of Fatigue in Mine Laborers. This Jour., 1922–1923, *4*, 90.
11. Harrington, D.: Underground Ventilation at Butte. U. S. Bur. Mines, Bull. 204, 1923, p. 105.
12. Lewis, R. S.: Some Kata-Thermometer Observations in Tonapah Mines, Nevada. Engin. and Min. Jour. Press, 1924, p. 364.
13. Vernon, H. M.: The Kata-Thermometer in Studies of Body Heat and Efficiency. Part V. The Index of Comfort at High Atmospheric Temperatures. Med. Res. Council, Special Rep. Series No. 73, p. 116. London, H. M. Stationery Office, 1923.
14. Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds. Minutes of Evidence, 1909 (Cd. 4485), p. 87.
15. Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds. Second Report, 1911 (Cd. 5566). Appendix II, p. 22.
16. Wyatt, S.: Variations in Efficiency in Cotton Weaving. Indust. Fatigue Res. Board, Rep. No. 23, p. 15. London, H. M. Stationery Office, 1923.
17. Weston, H. C.: A Study of Efficiency in Fine Linen Weaving. Indust. Fatigue Res. Board, Rep. No. 20, p. 25. London, H. M. Stationery Office, 1922.
18. Daley, W. A.: Annual Report upon the Health of Blackburn (1923).
19. Sutton, H.: The Influence of High Temperatures on the Human Body, Especially with Regard to Heat-Stroke. Jour. Path. and Bacteriol., 1909, *13*, 62.
20. Vernon, H. M., and Bedford, T.: Two Investigations in Potters' Shops. Indust. Fatigue Res. Board, Rep. No. 18. London, H. M. Stationery Office, 1922.
21. For a detailed account of American researches see Jour. Am. Soc. Heating and Ventil. Eng., 1923, *29*, 129, 165, 515; 1924, *30*, 169, 199, 453, 597.